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Bachelor of Engineering Thesis

Cost Effective Utilisation of Spilled Renewable Energy

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Abstract

Renewable energy has become the focus of governments and societies around the world as the push to provide sustainable electricity generation gathers strength. As renewable energy penetration becomes higher, more renewable electricity will be spilled without large scale economic storage. This thesis examines potential ways that spilled renewable energy could be economically utilised.

The newly installed renewable diesel hybrid power station at Coober Pedy, SA, operated by Energy Developments Limited (EDL) was the trial case examined. Separated from the grid and pushing 70% renewable penetration, the system was modelled to determine how much renewable energy would be spilled each year. Analysis showed that on average 8.8GWh of renewable energy would be spilled at the site each year, approximately 49% of renewable production.

It was decided that this spilled power would be used to operate a greenhouse for the town. The results for this scenario were not promising, with the greenhouse unable to run on spilled energy alone regardless of size. The introduction of dispatchable power through a battery or diesel allowed the greenhouse to operate year round. However, it was determined that despite the technical feasibility of the project, it was not economically viable. The high cost of battery storage and diesel, Levelized Cost of Electricity (LCOE) of over $1000/MWh for batteries and $329.7/MWh for diesel resulted in no positive Net Present Value (NPV) projects. To achieve a positive result the LCOE of the dispatchable power needed to be closer to the cost of grid power, approximately $103.91/MWh.

The key findings of the study show that with current cost structures using spilled energy to supply a greenhouse with power is not economically viable for the remote town of Coober Pedy.

Acknowledgements

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1.0 Introduction

With the signing of the Paris climate agreement, Australia has committed to reducing carbon emissions by 26%-28% on 2005 emission levels [1]. From an electricity generation perspective this equates to 33 TWh of renewable energy by 2020 [2] and significant further growth in the industry for the next decade. There are some major barriers to the rapid expansion of renewables particularly surrounding the capital expenditure cost and the cost of producing electricity. The levelized cost of electricity (LCOE) for renewables has been rapidly falling in recent years, becoming as cost competitive as traditional fossil fuels and in some cases cheaper [3]. Lazard's LCOE analysis uses their industry knowledge as one of the leading financial advisory and asset management firms in America to gather data across a wide range of operations and projects. The recent Lazard LCOE Analysis (the tenth in the series) shows that in the United States the cost to produce wind or utility scale power has become less than both coal and natural gas as shown in Figure 1.

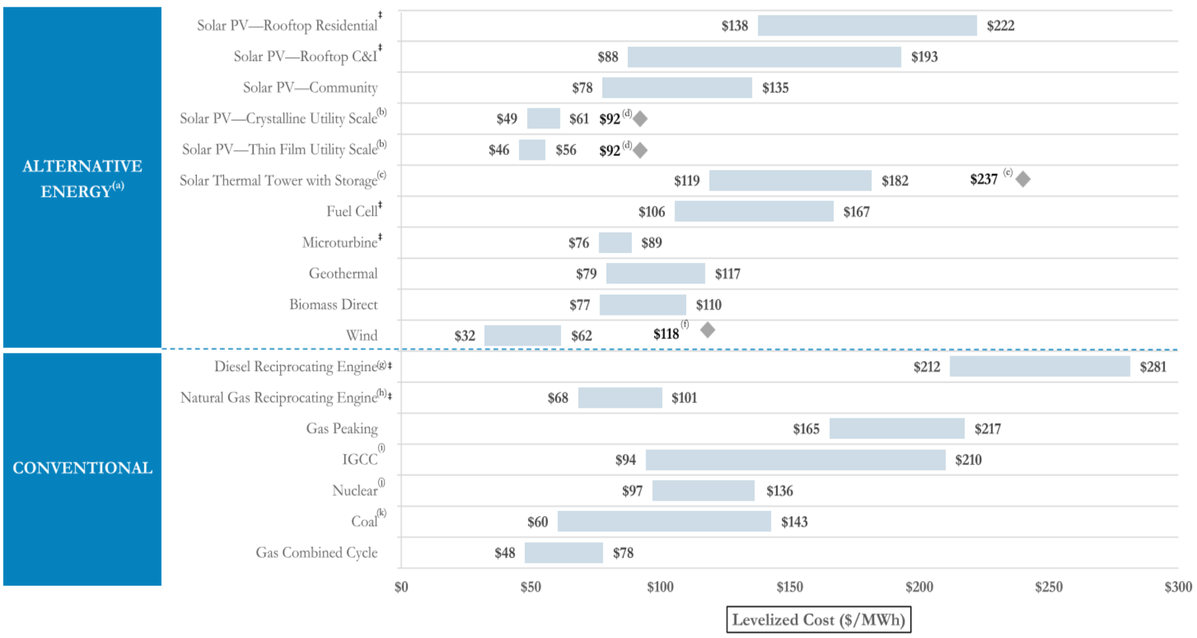


Figure 1 *- Lazard's Unsubsidised Levelized Cost of Electricity for Alternative and Conventional power sources. These values do not take into account social, environmental, reliability or intermittency-related considerations [3].*

In Australia, the situation is different with recent government reports projecting that without government subsidy, only onshore wind power is directly competitive with fossil fuels in the near future, with fixed solar and other technologies lagging behind [4]. Without a reduction in LCOE or a continuation of government subsidies, Australia's emissions target will be difficult to obtain through direct capital investment.

High unsubsidised LCOE is just part of the issue stopping rapid advancement of renewable investment. Intermittent supply is the most significant hurdle to overcome and currently there are very few cost-competitive ways to solve this. Renewable energy supply can drop suddenly leaving a shortfall of electricity with little time for other sources to react to meet demand. In some instances the solar resource can drop by as much as 60% within a ten second period [5]. To maintain reliability and high penetration, installations of renewable energy in small sized grids need to be oversized [6], meaning higher capital costs and an increase in LCOE [7]. Additionally, this oversizing results in energy being spilled (energy which is not used by an active load and is then dumped). In some cases previous research has shown this can be up to 35% of energy generated [7]. While it is possible to store this energy in batteries, the technology has not progressed to a point where it is cost effective to implement on a small scale. The Lazard report indicates that mixing the battery and renewable technologies brings the cost of producing electricity in line with fossil fuels [3]. In Australia, the effect takes renewable out of contention with fossil fuels.

These issues are of particular interest to Energy Developments Limited (EDL) and their renewable-hybrid power station in the remote town of Coober Pedy. The town which is well known for its opal mines will be receiving a power station upgrade to shift it from the current diesel only generation to a solar-wind-battery-diesel hybrid. The power station currently has a continuous power rating of 4.28MW (only diesel), but will be receiving a 5MW renewable upgrade. This will lead to a targeted 70% renewable penetration over the next 20 years of operation. However, due to the town being solely reliant on the power station for its energy needs, the size of renewable energy installed is far greater than the average load of 1.5MW. This will lead to the renewable sources at the station producing 16GWhs of power during the year, of which half is likely to be spilled. If this amount was able to be reduced or used for another purpose the high capital costs involved in the installation of the project would be far more favourable.

To ensure the transition of Australia's energy supply to renewable sources utilising spilled energy for additional economic gain is a way to increase the cost effectiveness of current generation and storage technologies without large amounts of capital expenditure. This report aims to summarise the current technologies available and focus on ones of particular interest to the Coober Pedy project. The objectives and benefits of the research will be clearly outlined and the plan going forward completed.

1.1 Project Objectives

The objectives of this thesis is to determine if there is a solution available to current renewable energy investors which can increase the feasibility of producing renewable electricity and overall profitability by using spilled energy from renewable energy. Specifically it will model the potential for a closed greenhouse to provide an alternate revenue stream to the power station in the remote town of Coober Pedy. The objectives are as follows:

- Establish the feasibility of growing tomatoes in a closed greenhouse environment using only intermittent power supply that is provided by spilled energy.
- Develop a model to size closed greenhouses for a given amount of spilled energy.
- Determine if the growing of crops in the greenhouse provides a positive cash flow effect on the overall power system (renewable-diesel-greenhouse hybrid).
- Determine if the cost of the greenhouse and return from the crops provides a superior equity return on investment then without it.
- Identify potential areas for further research and investigation.

Success with these objectives will provide another avenue for development of renewable energy projects in Australia and provide a way for remote communities to live sustainably.

1.2 Scope of Work

The scope of work will focus on the microgrid community of Coober Pedy and the power demand profile of the town versus the supply.

1.2.1 Inclusions in the Scope

The following activities are included in the scope of work:

- Review of current literature and existing solutions including battery storage, hydrogen fuel cell technology, storage through heating and cooling systems and current microgrid technologies.
- Analysis of the power demand at Coober Pedy.
- Determination of the wind and solar resources available and modelling of the potential daily, monthly and annual yields.

- Data collection from the Coober Pedy power station to verify the predicted amount of spilled power available
- Model the spilled energy produced against the energy required to grow crops of tomatoes in a closed greenhouse environment to determine the size of the greenhouse possible.
- Financial modelling of the renewable-diesel-greenhouse power system
- Comparison of the ‘business as usual’ case versus the renewable-diesel-greenhouse case
- Recommendations on potential further research and development.

1.2.2 Exclusions from the scope

The following work is excluded from the scope:

- Design of the closed greenhouse
- External supply issues to the greenhouse such as water
- Analysis of the market demand for tomatoes
- Detailed operations and maintenance guide for the greenhouse
- Development and Land tenure issues
- Analysis of greenhouse ability to grow plants on other power station configurations
- Analysis of the spilled renewable energy for other power station configurations

The scope will only extended to the theoretical potential for this greenhouse system to function properly and provide a positive impact, and will not delve into the details of developing and continued operation of the system.

2.0 Literature Review

To form a base of existing solutions to the problem at hand a review of the relevant research and prior examples has been undertaken. This involved research into:

- Microgrids
- Spilled energy in microgrids
- Energy storage techniques
- Alternative uses for spilled power and
- Energy management

2.1 Microgrids

Microgrids are power systems made up of distributed power sources, with potentially controllable loads deployed across a limited geographic area [8]. In modern Australian terms, they are power systems which are made up of either diesel or gas generation or a mixture of diesel or gas and renewables, to meet the energy demands of a small remote community. These are often separate from the grid authority and are wholly reliant of the microgrid operator's ability to provide consistent and reliable power supply. Microgrids are not a new idea, there are many in operation globally, with EDL operating numerous remote and isolated energy power stations across Australia for a number of years. This makes EDL's operational microgrid capacity approximately 355MW of installed generation across 28 sites ranging from 200kW to 78MW solutions [9]. On a global scale, current estimates of the amount of microgrid generation installed is around 16,582MW, as per Navigant Research's (a global research company) quarterly microgrid capacity tracking report [10]. While this is only a small proportion of the total global demand, Circa 22,000 TWh versus 28 TWh locally, [11] there is an increasing demand for innovative and sustainable energy solutions to transition the energy supply.

In recent times the shift towards sustainability has prompted research into introducing renewables to the microgrid energy mix as a way to reduce costs and fossil fuel consumption [12, 13]. Because of Australia's dispersed population and large landmass the option of microgrids are often the ideal solution for remote communities in Australia as opposed to becoming connected to the national grid. AEMO already operates one of the largest and most reliable grids in the world [14], covering the entire Eastern seaboard of Australia.

Figure 2 *- AEMO Transmission Grid [15].*

The operation and expansion of this system can be extremely costly and complex and so connecting remote locations to the grid energy system is too high when compared to the renewable-hybrid, microgrid option [13]. It is expected by AEMO that by rolling out more microgrid solutions to remote locations, up to $16.2 billion dollars in network investment could be saved [14]. The advantages of introducing renewables to these remote communities is the decreased maintenance, future cost reduction and the ability to quickly expand production for growing energy needs [12]. As the cost of renewable generation reduces, the savings can be passed onto the consumer, giving them greater control over the negotiation of power prices.

Other than just a financial aspect, the environmental benefits of microgrids has also been proven, especially for very isolated areas [16]. Smith, C et al. conducted environmental modelling comparing connecting an isolated Thai island, Koh Jig, to the grid in comparison with installing a hybrid microgrid or remote diesel generation. The PV-Wind-Diesel Microgrid had a global warming potential of 1.23E+06 kgCO_2 compared to the grid extension which had a potential of 2.36E+06 kgCO_2, almost double the microgrid option. These were both well below the option for diesel generation. Given the grid connection was only for four kilometres of cable, the competitiveness of microgrids in remote energy over grid connected renewables to achieve environmental sustainability is clear.

Remote communities are not the only way to form a microgrid, the option to create microgrids within large metropolitan areas is something to be considered. With the emergence of rooftop solar and residential power storage, there is the opportunity to create small community power grids. By leveraging existing solar rooftop installations and the batteries available, with the installation of a centralised control hub and some additional generation units, a community or suburb could be turned into a microgrid [17].

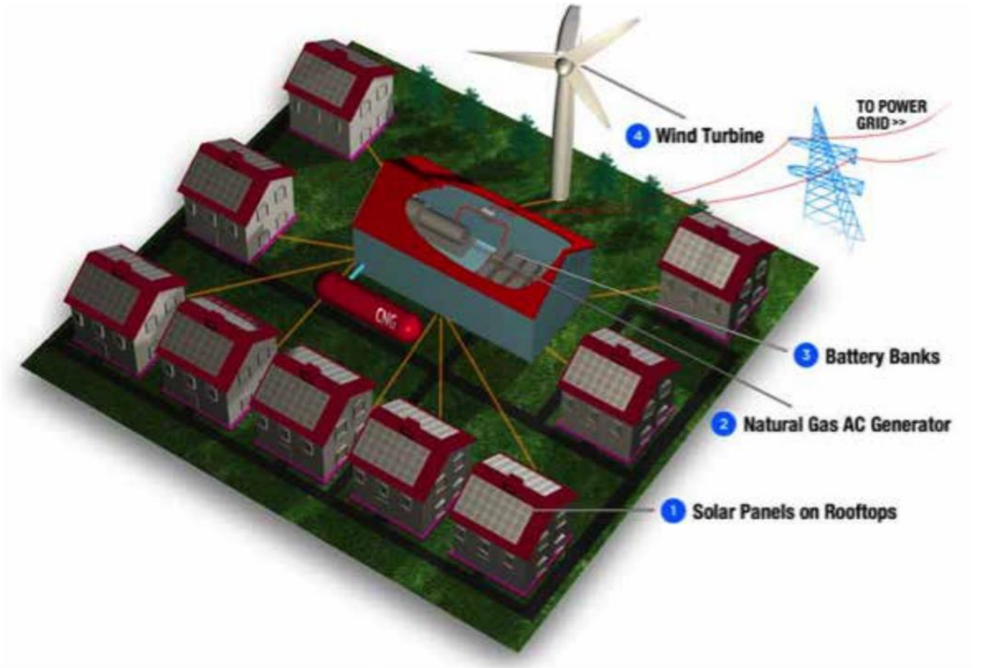


Figure 3 *- Simple representation of a neighbourhood microgrid, where the central natural gas generator and control system balances the load [17].*

However, with the need for greater cost reductions and community involvement to make this happen, isolated areas are the prime target for microgrid adoption. For towns such as Coober Pedy that is isolated from the grid the opportunity to create a hybrid microgrid is beneficial to the town and this has been identified as such [13].

2.2 Intermittency and Energy Spilled

As mentioned previously the issue with renewable energy is its intermittent nature and this is no different in a microgrid situation. Despite the research into the subject there is no clear cut solution which retains cost competitiveness against fossil fuels for renewables. The following details some of the findings of relevant research articles into microgrids and the amount of energy they spill.

For a microgrid design in Gokceada, Turkey, a wind-battery system was studied and in the scenario the energy spilled was 64.2% of the total produced [18]. This is quite a similar town to Coober Pedy, the town population is comparable, the climate is similar and the demand profile is of the same magnitude. What the study did show was that it is possible to supply energy cheaper than diesel with a mixture of renewables, however, it does not supply a solution for the huge amounts of energy being spilled. With a proper strategy for this spilled energy, additional value for the community could be developed. In India another study was carried out at a remote location consisting of a PV-wind-hydropower and bio-diesel microgrid. This scenario showed that the amount of spilled energy was in the region of 25% of total generated power [19]. This town modelled is not of comparable size and demand profile to Coober Pedy, but it does add to the point that even at low penetrations of renewables (PV and biodiesel constitutes 24% of the supply in this study, Coober Pedy close to 70% penetration) there is still a substantial amount of energy being wasted. Ipsakis, D et al. carried out an analysis on a standalone solar and wind system in Greece and found that up to 56.4% of the time there was available energy to be used for other sources [20]. In this case it was used for hydrogen generation, which will be addressed later on in this report. One excellent piece of research was conducted in Waterloo Ontario, which had an existing diesel microgrid supplying the community with around 5000 kWh/day (about half of Coober Pedy) [21]. The study modelled four different scenarios, the existing diesel supply, an entirely renewable power system, a diesel-renewable hybrid and a grid connected option. The cases of most interest are the entirely renewable and diesel-renewable hybrid scenarios having renewable contributions of 100% and 53.8% and energy spilled of 70.5% and 16.86% respectively. What can be taken from this study is that with higher penetration of renewable energy comes a greater spill load. The only reason that this study is not directly comparable with Coober Pedy is that the method they used for meeting demand does not take into account second by second reliability of the grid, but rather considers by hour. The added stability factor reduces the cost effectiveness and requires greater renewable resources. Similar study at a lower penetration (21%) was carried out for a diesel-battery-PV system in Saudi Arabia and only 0.67% of the energy was spilled. However, if the penetration levels increase to 42% the spilled energy increases to 10% [22]. Supporting this article is another from the Saudi Arabia region that concluded that excess energy is directly related to an increase in PV penetration of a PV-battery-diesel hybrid system (shown in Figure 4) [23].

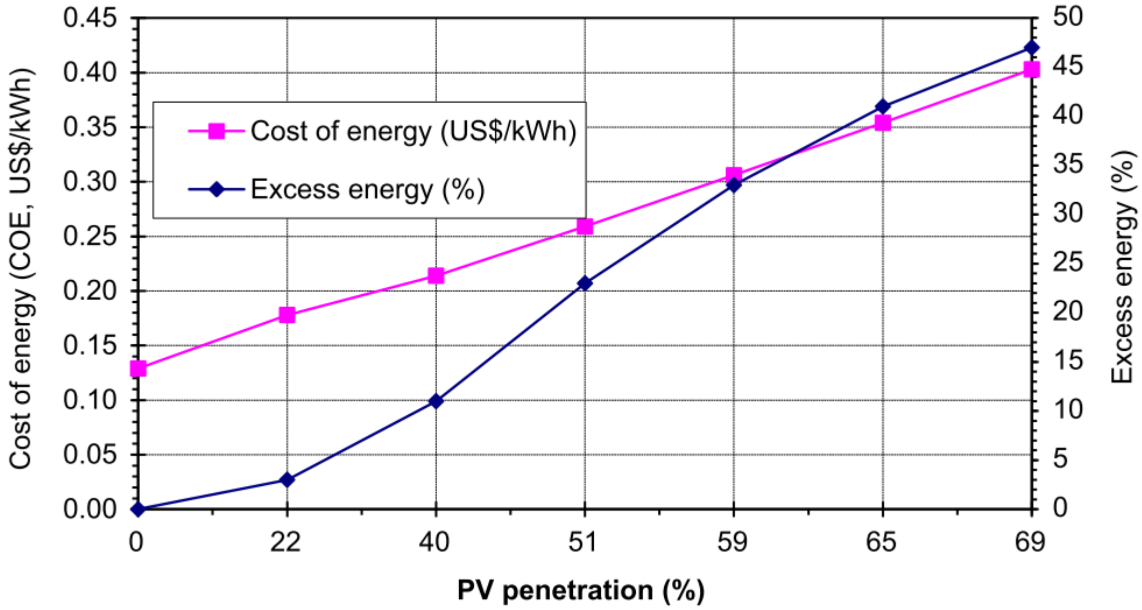


Figure 4 *- Impact of higher PV penetration on the COE and Excess energy for a hybrid renewable system [23].*

This is important to the progress of renewable deployment because these studies show that sizing a microgrid system to suit a certain demand at the most cost effective level will still result in large amounts of spilled energy. However, they show that spill can be managed through a battery, but did not address the cost effectiveness of the solution in comparison to other methods. There is a great potential for this energy to be used in an alternate way to help increase the attractiveness of renewable energy. The following sections discuss some of the researched methods.

2.3 Microgrids and Storage

Battery storage is one of the most sought after solutions in recent times. The ability to control the load, stabilise supply and increase efficiency are the main benefits of batteries. Unfortunately the cost of the systems is not competitive on a small scale at the moment. For a microgrid or islanded system the levelized cost to store (LCOS) energy in a lithium-ion battery ranges from 372 – 923 $/MWh [24]. If compared with Lazard's LCOE for normal generation, this is above the levels of remote diesel generation and undercutting the effectiveness of the solar and wind efficiency [3, 24]. The Lazard LCOE analysis shows the addition of battery storage doubles the LCOE of solar and wind power (unsubsidised) [3]. In this study it shows that both of the renewables still operate at a cost lower than that of diesel, but these are for standalone utility-scale systems and do not factor in the requirement of reliability and intermittency management schemes. With these additional costs renewable-battery systems operate at around the same cost for a microgrid, but the high initial capital costs for the system make it undesirable for investors [21]. These capital costs are likely to fall over the next five years (Figure 5) by 38% [24], but this is not an immediate solution and will still require large capital investment. However, there are still other issues constraining the ability of batteries to provide cheap and reliable power other than capital such as lifetime, charge and discharge rates and charging fractions (battery never reaching full change or fully emptying).

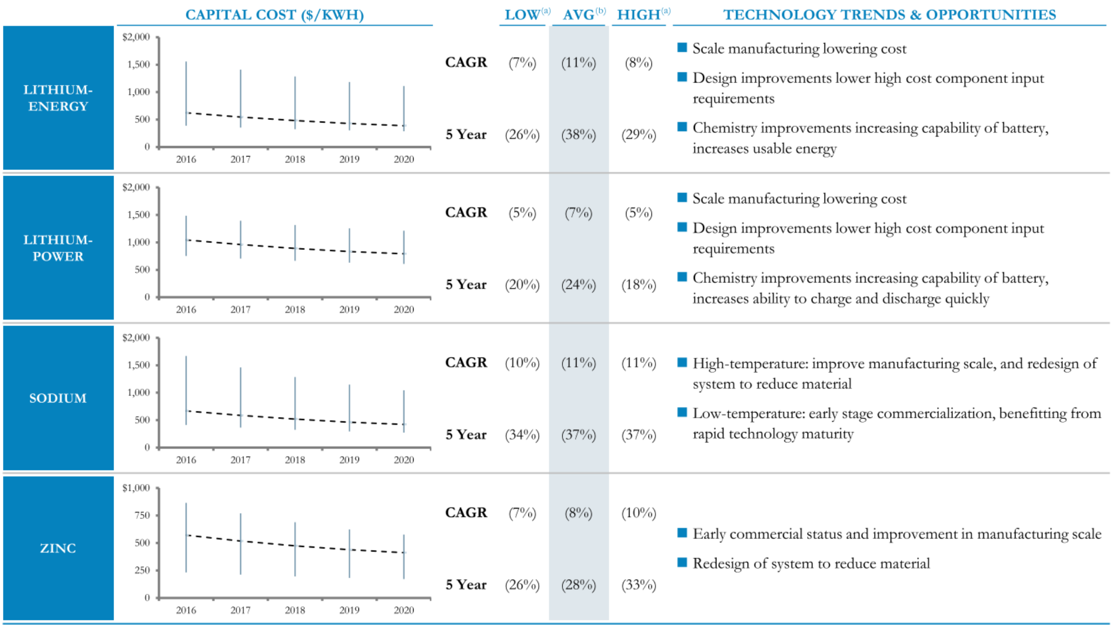


Figure 5 *- Forecast capital costs of battery storage [24]*

While battery storage systems are economical as a large scale grid solution as shown by AES Energy Storage [25], on a smaller scale where there is greater penetration and spill, this is still not economically viable. In non-grid connected systems like Coober Pedy, even with a battery which is used to help smooth the initial indications show that there will still be large amounts of renewable spilled throughout the year. The only reason the battery system is viable for Coober Pedy is because of government subsidies. Research has also shown that despite batteries there can still be significant spill, reducing the efficiency of the system and reducing cost effectiveness [21, 26]. This leaves other solutions to try and produce useful outcomes from this spillage.

2.4 Hydrogen Production and Storage

One of the more novel solutions is to create hydrogen from water for use in fuel cells. The process would use electrolysis to separate hydrogen from water. One study has modelled a scenario in Ontario, Canada which has a large amount of hydro and wind power stations which are very exposed to seasonal patterns [27]. This leads to large discrepancies in power production and leads to up to 3.31 TWh of renewable energy being wasted per year. The study modelled the cost to convert this to hydrogen and sell it back to the grid to replace coal power. The study showed that the system is economically feasible with a payback period of 17 years. Given the life of the system is designed for 20 years, this is a relatively poor return. While it is possible and does give a return, the profit is too small and too risky given the potential complications of the system for most investors to commit. The previously mentioned study by Ipsakis et. al. looked at optimising a power management strategy for a hybrid hydrogen system [20]. While the system was better designed than the Ontario study, they did not investigate cost of the system and so the only useful information from the study was to do with control of the system. The biggest issue that is not addressed in these papers is that without a market for the hydrogen to be sold to, producing it is pointless. The producer could consume the hydrogen themselves, but this adds another layer of complexity to the system and for very little gain [27]. At Coober Pedy, hydrogen could be produced but there is no market for it and the economics of the project would make it unfeasible. Without further development of a market or technologies, hydrogen production through spilled energy is not a practical solution.

2.5 Demand Management

Demand management is a concept that has been gaining popularity in recent years. With the power price fluctuations in South Australia becoming a major issue for the state, the generation mix and ways to reduce cost have come under scrutiny [28]. The difference between the demand during the day and during the evening causes fluctuations in power price level and puts pressure on the supply side, particularly in the case of renewables. In the case of Coober Pedy this can represent a 30% increase in demand. As the supply of solar is dropping off, the demand starts to pick up and the wind is not always consistent, diesel generation is often used to cover the shortfall. One of the technically simple ways to do this is through demand side management, which was also suggested by AEMO as a way to help manage the South Australia price problems [28]. This process involves customers managing when they consume power and switching certain appliances off such as pool pumps or heaters, or run them during low-demand periods to stabilise the grid. The proposal AEMO has put forward is for a system where the consumer is provided with a tariff for reducing the demand during peak times, when they previously would use it [29]. While not yet implemented, there is potential for it to reduce the peak load of the grid as shown by a trial conducted by United Energy, an Australian grid operator [30]. Across a trial period during summer customers of United Energy were provided with an app which would help them identify periods where it was beneficial to reduce their energy load. As a reward, the customers we given financial incentives to switch off during peak events, like the summer heat waves. If the customers met their energy target set by United Energy, they received a $25 dollar payment. The program was able to reduce the peak load for these customers by an average of 30% and even lead to better customer satisfaction and engagement. While this does show a strong indication of the potential success of demand management, the trial was only on a limited basis and the reward offered is not likely suitable to a long term approach. More investigation into whether the same response can be gained from a larger audience with a different reward is still to be investigated in the Australian Market.

The potentially more effective method of demand management is through automated control of manageable loads, creating a Smart Grid. These industrial or residential loads are in communication with the grid operator to allow rapid demand management without reducing the quality of the product. There are a few ways this has been approached with one notable study conducted focusing on the control of electric water heaters [31]. The study, based in the north west of America, took control of approximately 100 heaters (residential) with a few industrial sized also included. By maintaining the temperature of the tanks between 90 and 170^{o}F the program was able to 'flatten' the load profile which allows for better energy forecasting. The eventual goal of this program was to help reach the generation target of 50% wind generation. In a similar vein of research, the same method was applied to industrial cold storage through a joint venture of VersaCold, a refrigeration company and EnerNOC [31, 32]. Using the same approach of containing refrigerator temperatures between acceptable temperature ranges, the program was able to save 3.2 MWh per annum. This was across twelve of Versacold's sites with no effect on the quality of the goods stored. The same concept was investigated by CSIRO for a cold-storage facility in Newcastle, Australia [33]. This control system took the idea slightly further than those previously mentioned by taking into account the cost of electricity and external conditions to minimise operating costs and still reducing energy loading. This advanced method looked to predict the energy requirements hours or days in advanced based on forecasted data about the potential conditions. Using the model, the energy consumption of the 89 m^2 refrigeration system was reduced by 24.27% for an ambient temperature of 20°C and 30% for an ambient temperature of 30°C [33]. This was applied by other researchers to analyse a residential scenario, targeting the heating of water which often takes up a large portion of electricity consumption [34]. Through controlling the temperature of the water system, the researchers were able to save 23.4% of energy consumed [34]. This was a relatively simple control technique and if applied across a whole town could result in large energy savings. The only aspect the research falls short on is the community response to the changing of the water heating fluctuations. If the temperature is not the right temperature when the person needs it to be, they are unlikely to undertake the program. The model makes assumptions about the ideal temperature but this could change in different regions and towns resulting in poor uptake or community backlash.

The next stage in this research is for cost optimisation and community perceptions. With the successful case studies already discussed in this paper [31-33] there is clear evidence to suggest this would be a successful method of helping manage the intermittency of a microgrid by smoothing out the load and shifting it to periods of high renewable energy. Each of the case studies provided are real world applications and can be relied upon for their accuracy and integrity. There is definitely a case for using these techniques to help address the issues microgrids face, the major difficulties with the process lie with the willingness for consumers and industry to get involved in the process and the set up costs to develop the call and response communication system.

In a similar style of management, another method is to utilise services only when they are needed, or use them as a power storage system to utilise later. This can take the form of desalination, heat or cold storage or pumping water [35-42].

For many remote communities in arid climates such as Coober Pedy, water bores and desalination is the only way to secure a stable water source. Researchers have investigated the potential to use the desalination plant in a Saudi Arabian town to help manage the intermittency of the renewable energy supply [35]. The model created uses the desalination plant as a manageable load, altering the load to suit the conditions of the renewable energy available. For example in high renewable energy periods, the plant will run at full capacity and increase its stores of drinking water in anticipation of having to curtail production later. If the renewable energy resource suddenly drops, the plant is de-rated to stop the need for fossil fuels to come online to accommodate for the loss of power. During this de-rate period the station is still able to supply the town with water because of the reserves that it amassed during the high renewable period. In this sense the plant acts like a battery. The model that was developed in this paper was able to achieve a 12% cost reduction [35]. This study was modelled over a variety of sites across Saudi Arabia and also took into account ensuring that the town's water supply was never compromised, based off historical demand and future demand growth. This type of solution would be extremely applicable to Coober Pedy, which operates a desalination plant which consumes a large portion of the power produced. The only drawback of the solution is the ability to work with the operator of the desalination plant to make the system work. The model created relies upon the almost instantaneous change in the operation of the plant and the change in renewable supply, which could be established through internet connection and a control system, but without the cooperation of the plant, this is not possible.

On a similar note, a project dubbed "Night Wind" conducted in Demark aimed to use mass refrigeration to store the energy produced by the excess wind energy produced at night [36]. This project used the Night Wind Control System to manage when to store energy versus when to release it. The excess power would be stored in the refrigeration units by taking the temperature to the limit before the product began to degrade (the coldest it could handle). It would then maintain this temperature using the excess wind energy and then release the energy during periods of peak power usage. The idea was to cut off the peak of the daily energy demand cycle and thus reduce peaking power prices for consumers.

The other area considered is to run services when excess energy is available, for example irrigation systems and water pumping. This is of particular interest to farmers in the Mediterranean who are exposed to high sun levels and often remote locations for farming such as the Greek islands [37]. These regions are big users of drip farming and it is important that the right amount of water is available at the right time in order for proper crop growth. The study by Carroquino, Duf-Lopez and Bernal-Agustin examined this issue and how they could use renewable power to cut diesel costs for remote locations [37]. What it found was that a solar array was not able to effectively run the system alone, but rather a diesel-hybrid approach was the most cost effective. Similarly, Ramazan looks at the use of solar pumps to control the irrigation system in farms in Turkey [38]. Over the life-cycle of the system, a PV powered pumping system will outperform a diesel system according to research, however, this is only exposed to one site and hasn't assess different locations. Other sources look at the ability for the pump to supply the necessary water to keep the plants alive, even if some run on a deficit irrigation scheme [39-42]. What is found was that given the right plant, a very intermittent load could still supply the pumps with enough power to supply water to the crops. In some instances, there were long periods of time where the plants were without enough power to fully satisfy the conditions, but enough to keep the plants alive until more renewable energy was available [41]. This sort of research could be easily transferred to size an irrigation system attached to a microgrid. The system would be operational when the microgrid was spilling power, using otherwise wasted energy to create a farm. With the diesel generation units to supply emergency power, it is entirely possible to create a farm given the right environmental conditions. Whether this is a cost effective solution is yet to be determined, there is no known instance where a farm has been powered entirely by spilled energy from a microgrid. The closest application is Sundrop's farms which are powered by a dedicated solar thermal-battery system, sized specifically for their farm [43]. The farms that Sundrop have operational are able to run entirely off renewable energy, but they have created their own power station around the greenhouse to do it, additionally they have a reliable connection to the NEM grid. It is highly likely that they are spilling large amounts of energy to ensure the stability of the growing process. This is a potential application for spilled energy usage, but the practicality and economic viability is still to be tested.

Demand management is a multi-facet strategy and there are many ideas and strategies which fall under the umbrella. The main hurdle to making these strategies a reality is the community. With many of these strategies relying on community involvement, the incentive for the consumer must be clear for them to get involved. The most effective form of demand management would be one where the implementation is separate from the community and will not affect their day to day lives. For this reason, strategies such as the desalination [35] and industrial refrigeration [33, 36] are particularly promising. All of these approaches use control systems of sorts and this highlights the need for proper optimisation of microgrids.

2.6 Optimisation of Microgrids

One of the biggest areas of research in microgrids in recent times has been with their optimisation to maximise their operational efficiency through control systems. This is at times combined with demand management strategies, which is in some respects another form of optimisation or control. The optimisation techniques that have been researched include genetic algorithms, direct deterministic algorithm, particle swarm optimisation, simulated annealing, neural networks, simplex algorithms and Cuckoo search optimisation [6, 44-48]. Derakhsan, G., H.A. Shayanfar, and A. Kazemi, developed an approach to try and address the intermittancy issues by creating an algorithm which focuses on economic efficiency, reliability and environmental imact [44]. The algorithm was found to help increase the efficiency of a hybrid system with little investment. In a client focused study on the Leaf community in Italy, Provata et al. created a genetic algorithm model to minimise the cost for end users [45]. One research article looked at how to incetivise customer involvement through a demand response program [46]. The demand response program implemented in the article was found to reduce operational cost and improve overall operations. The only drawback from this case was that it was still connected to the grid and so wasn't a true isolated microgrid. The mircrogrid simulated ended up relying on the grid and the conventional power too often, which makes it not directly applicable to Coober Pedy.

The optimised location of a microgrid was briefly investigated and an algorithm developed by Foroutan, Moradi and Abedini [47]. At the time this was the first sort of optimisation based on finding suitable locations for microgrids and looked at first creating a suitable algorithm for an islanded microgrid. The authors stressed the importance for these locations to be able to minimise diesel fuel cost while also maintaining voltage stability. As a wind-diesel microgrid, this is applicable to Coober Pedy, the model was only theoretical and hasn't been applied to a practical solution but modelling suggested it kept voltage deviation tolerances within acceptable limits (0.5% - 5%) while still minimising diesel output.

Another study conducted on Jeju Island, Korea looked at determining the optimal combination and sizing for an isolated renewable energy hybrid [6]. The superstructure-based optimisation model developed considers the multiple types of energy available (solar, wind, diesel) and the also considers the distance between power sources and the cost and difficulty of transferring power at different times. The biggest finding in the study was that the addition of a battery to the system allowed for the optimisation process to become increasingly effective. Despite the large capital costs involved in the battery, the system was able to produce electricity cheaper than without a battery (0.409 $/kWh without a battery versus 0.361 $/kWh with a battery). The authors attribute this to two things, firstly without the battery the generation devices were oversized and overdesigned resulting in equally large capital costs. Secondly, given the flexibility of the storage option, the optimisation algorithm was able to use the battery's stored energy to effectively dispatch energy to avoid buying energy at inflated prices during high demand. When applied to the island this was greatly successful [6]. This is a potential opportunity for Coober Pedy to use the small storage it has to better optimise its dispatch to reduce cost of energy. This would be done during periods of high demand where the diesel generators need to be used, which is the highest cost factor for current residents.

Another optimisation study was carried out to find the optimal size and cost of a microgrid based on the energy market and the ability of the microgrid to trade on the market [48]. The algorithm uses a Particle Swarm Optimisation approach to trade energy to determine when it would be cheaper to produce isolated energy in a microgrid rather than buy it. The algorithm put forward was able to determine the optimal size of a microgrid for the market conditions proposed. While this was an interesting approach to sizing the system it is quite novel in that it only sized the system for one size, and didn't look at seeing if the algorithm was applicable for larger towns which have greater power demands. Additionally, the algorithm's ability to operate in the different energy markets around the world wasn't addressed and so while the concept of the optimisation algorithm proposed is good, its application to different scenarios is yet to be proven. As such it is still necessary to approach each microgrid as a separate case and design the system from there.

Optimisation is the final step in the design and development of the microgrid. There are many different optimisation techniques and algorithms available, but it is important to make sure that the right technique is used in the applicable situation. Depending on the end goal, i.e. diesel usage minimisation, or cost of electricity, the type of model changes and so there is no overarching optimisation technique which is superior to the others. Some of these techniques could be applied to Coober Pedy, but it is important to ensure the goals of that optimisation process align with the goals of the stakeholders.

3.0 Coober Pedy – Power Supply and Demand

3.1 Supply

The following section outlines the supply mechanisms which are available to the town of Coober Pedy and the potential supply of spilled renewable energy available.

3.1.1 Power system overview

Coober Pedy's power supply is incredibly specific to the town's needs and growth for both industry and population. Because of its remote location, approximately 700 kms northwest of Adelaide, the town is not connected to South Australia's grid network which is part of the National Electricity Market (NEM). As such, EDL owns and operates the Coober Pedy power station which supplies the town with electricity, which is then distributed through the District Council of Coober Pedy's (DCCP) energy network. EDL sells the power to the Council, which in turn distributes and charges the citizens of Coober Pedy. The power station is fully 'islanded' from the national grid and if the station goes down the entire town loses power.

As part of Australia's movement towards a more sustainable power generation balance, ARENA engaged EDL to design, construct and commission and new power station to enhance the existing station as it came off contract. This new station would transition the old station from the diesel generation installed to a renewable-hybrid power station capable of 70% renewable penetration. As detailed in previous sections, this exposes the power station to issues surrounding reliability and so the design has been adjusted to handle this.

3.1.1.1 Existing Power station

The existing power station is entirely diesel based, consisting of eight Deutz 616 V12, reciprocating, diesel-fuelled 576kWe engines. Accounting for de-rate which occurs as a result of the increased intake manifold air temperature, the generators operate at a continuous power rating of 535kWe. This combines for a continuous site rating of 4,280 kWe. Table 1 gives details of the engines specifics.

Table 1 - Diesel Engine Specifications [49, 50]

Factor	Value	Units
Make and Model	Deutz 616 V12	
Speed	1500	RPM
Frequency	50	Hz
Rated Capacity	576	kWe

Fuel consumption (100% capacity)	191 : 8289.4	g/kWh : kJ/kWh (LHV)
Fuel consumption (75% capacity)	191 : 8289.4	g/kWh : kJ/kWh (LHV)
Fuel consumption (50% capacity)	196 : 8506.4	g/kWh : kJ/kWh (LHV)
Efficiency (100% load)	43.43	%
Efficiency (75% load)	43.43	%
Efficiency (50% load)	42.32	%

These generators are controlled through a PLC and will normally share the load across the generator systems, with some being left on standby as 'spinning reserve' in case of a rapid increase in demand, or the malfunction of an on-duty engine. Spinning reserve is important for the reliability of the system, in that the engines designated as spinning reserve must be able to ramp up to the power output necessary to cover power losses or demand increases rapidly to ensure no loss of power to the town. The engines output power at 415V, 50Hz which is stepped up to 6.6kV and distributed to the town through two feeders.

In a year, the power station will emit around 8,500 – 9,000 tCO_2 and is still very exposed to diesel prices which are inflated given the remoteness of the town. Current Diesel prices in the town are 145 c/L [51] compared with the average in Adelaide of 118.6 c/L [51] (22.25% increase). This will often lead to fluctuating power prices and requires the government to step in and subsidise the prices. At the moment the South Australian government has pledged to subsidise the cost of electricity in Coober Pedy to keep in on parity with the rest of South Australia [52]. As such, with the existing contract up for negotiation the power station configuration has been upgraded to minimise exposure to diesel and reduce carbon emissions for the next 25 years.

3.1.1.2 Renewable-Diesel Hybrid

This power station upgrade comes in the form of a renewable-diesel hybrid which consists of four components: a 1MW solar PV array, 4.1MW of wind, 1MW battery storage and the existing diesel generators. The goal of this is to achieve a minimum of 70% renewable energy for the town across the year which can reduce emissions by around 6,500 tCO_2 per year, or 162,500 tCO_2 across the 25 year lifetime. The system will operate on the basis of maximising the amount of renewables used at any one time. This de-prioritises the diesel engines which will only be used when there is insufficient renewable energy available. The specifications of the various components are displayed in Table 2.

Table 2 - Renewable Hybrid Components Specifications [50, 53]

Factor	Value	Units
Wind Turbines		
Make and Model	Senvion MM92	
Rated Capacity	2050	kWe
Rotor diameter	92.5	m
Hub Height	80	m
Cut-in wind speed	3	m/s
Cut-out wind speed	24	m/s
Solar Panel		
Make and Model	First Solar - 4107 A-2	
Module Type	Thin Film	
Tilt angle	25	Degrees
Unit Nom. Power	107.5	Wp
Inverter	Sunny Central 1000CP XT	
Battery		
Make and Model	Toshiba SCiB	
Discharge/Charge	1	MWe
Storage Capacity	492.8	kWh
Conversion efficiency	90	%

Combined these components add up to be able to produce a maximum renewable power output of 6.1MW. However, this total is unlikely to eventuate as the battery will only be used as a stabilising mechanism in the event of a sudden energy drop. If a cloud rapidly covers the solar array or the wind suddenly drops off, the diesel engines do not have the capability to start in time to cover the loss. In this instance the battery is used to bridge the gap between the renewable energy drop-off and the start of the more stable diesel engine. This is the reason for the small storage capacity of the battery, which could only produce 1MW for 30 minutes. As such, the power station has three operating scenarios:

1. **Normal Operation:**

   Solar and wind resources are medium to high, with low variability. Power station fully prioritises the renewable energy and will use all the renewable available with diesel generation to provide any gap between demand and renewable supply. In this mode, diesel generation will be kept as spinning reserve, operating in standby mode to allow for rapid ramp up of generation if required (ramp up time is around 10-30 seconds).

2. **High Renewable Variability Operation:**

   When the variability of the renewable power becomes too unstable to support the 10-30 second ramp up period, the battery will take precedence over the diesel generation, and provide the generation gap for the time required to ramp the diesel engine up to cover the renewable loss. Renewable energy is still prioritised in this instant and will be used first before diesel generation.

3. **No Renewable Energy or Manual Operation Mode:**

   If there is no renewable energy available or the renewable energy is too unstable to supply the town, the power station can still run entirely on diesel generation as controlled by the site operator. Enough diesel engine generation has been left on site to supply the town to the maximum possible demand.

This system uses the existing distribution infrastructure and supplies 6.6 kV electricity through the two feeders (one for the hospital, one for the town). The diesel engines are the same as the existing station and have not been retrofitted for the new power station, only maintained as outlined in their operating manuals.

It is evident that the new power station is heavily reliant on the balance of renewable resources available and the supply that the town needs. The details of this supply will be laid out in the following sections.

3.1.2 Solar Energy Resource Review

Coober Pedy is a town that is in a very arid part of Australia, receiving little rain and often seeing soaring temperatures throughout the summer period. This makes it a strong candidate for large scale solar to supply stable power throughout the day to the town. There are a few different sources of data on the energy resource available, an 80 kW solar array on the desalination plant, historical energy analysis from the bureau of meteorology and the solar modelling program PVsyst. These resources have been assessed to determine a typical day at Coober Pedy and also the differences in seasonal generation.

3.1.2.1 Historical Weather Details

All data from this section was gathered from the bureau of meteorology, using stations 016007 (Coober Pedy) and 016090 (Coober Pedy Airport). Coober Pedy is extremely dry receiving only 142mm of rain on average a year. Table 3 shows the average monthly rainfall at Coober Pedy based on 96 years of rainfall data (see Appendix A – Coober Pedy Rainfall for further details):

Table 3 - Average monthly rainfall data Coober Pedy

Month	Average Monthly Rainfall (mm)
January	14.60
February	20.20
March	12.82
April	7.30
May	13.07
June	12.50
July	6.87
August	7.70
September	8.22
October	12.63
November	10.67
December	15.53
Total	142.15

As such the town is very reliant on bore water which is desalinated in town, however water supply is not part of the thesis scope and so the important data is the amount of cloudy days. Table 4 details the amount of cloudy days for the past year (May 2016 to May 2017) and indicates the relative amount of cloud cover.

Table 4 - Number of cloud occurrences at Coober Pedy from May 2016 - May 2017

Percentage Coverage at 9am	Number of Occurrences	Percentage Coverage at 3pm	Number of Occurrences
13%	10	13%	25
25%	8	25%	11
38%	3	38%	16
50%	6	50%	5
63%	6	63%	7
75%	6	75%	5
88%	26	88%	21
100%	67	100%	51
SUM	**132**	**SUM**	**141**

However, give that these are just measurements at 9am and 3pm in the day it is hard to judge the amount of cover during the middle of the day which is the most crucial time period for solar PV. Regardless, the data indicates that there could be up to 181 days during a year that there will be clouds in the sky (combining the 9am and 3pm observations), of which between 70-80% will have a sky coverage of greater than 50%. This means a third of the time the solar load is subject to variable loading.

In terms of temperature, the BOM has supplied 52 years of temperature data and the ranges of temperatures indicate a very hot climate. The maximum temperature, minimum temperature and relative humidity details are outlined in Table 5 and Table 6.

Table 5 - Average Maximum and Minimum Ambient Temperature

Month	Average Minimum Temperature (Degrees C°)	Average Maximum Temperature (Degrees C°)
Jan	18.1	34.3
Feb	20.0	34.8
Mar	17.3	31.3
Apr	13.4	26.4
May	9.9	21.7
Jun	6.9	17.9
Jul	6.0	17.7
Aug	7.2	20.5
Sep	9.6	24.2
Oct	12.9	28.1
Nov	16.1	31.4
Dec	17.1	32.4
Maximum Temp on Record		47.8
Minimum Temp on Record	-2	

Table 6 - Relative Humidity Coober Pedy

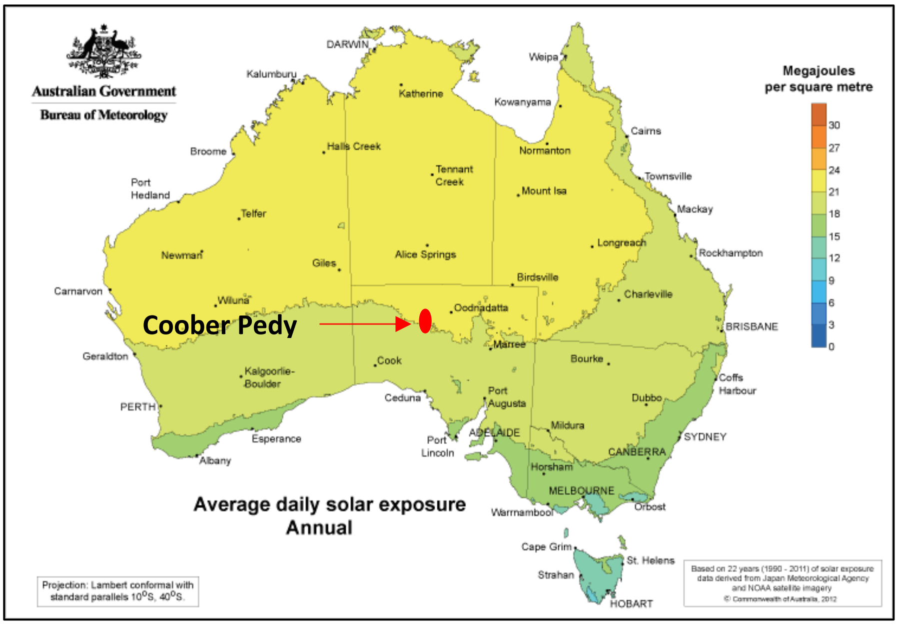
Month	Average Relative Humidity 9am (%)	Average Relative Humidity 3pm (%)
January	46.8	27.16
February	39.9	19.78
March	45.2	18.51
April	52.2	31.9
May	61.6	34.96
June	83.8	56.06
July	72.0	40.64

August	55.1	31.22
September	47.7	30.16
October	38.2	19.58
November	33.2	15.56
December	47.5	25.48

This data is more prevalent to the actual greenhouse growing process as it sets the baseload for the amount of climate management that has to be completed. What it shows is that while the temperatures may be relatively high in summer, the humidity is quite low, which makes it difficult to grow plants. In order to overcome this air quality will have to be managed well in order to control the temperature and humidity to maintain an optimal mix. This is looking at the issue from a greenhouse perspective but from a power generation point of view these details do not make a huge issue to production other than performance derate at temperature. All the power station components will be affected by high temperatures during the summer and this will have to be taken into consideration when modelling occurs. The most important part from a solar point of view is the amount of global irradiance available to produce power.

3.1.2.2 Solar Irradiance analysis

Solar irradiance is the measure of how much power you could get per square metre and is the defining factor for solar PV. Australia has a very high level of irradiance but this varies across the country as illustrated by Figure 6.



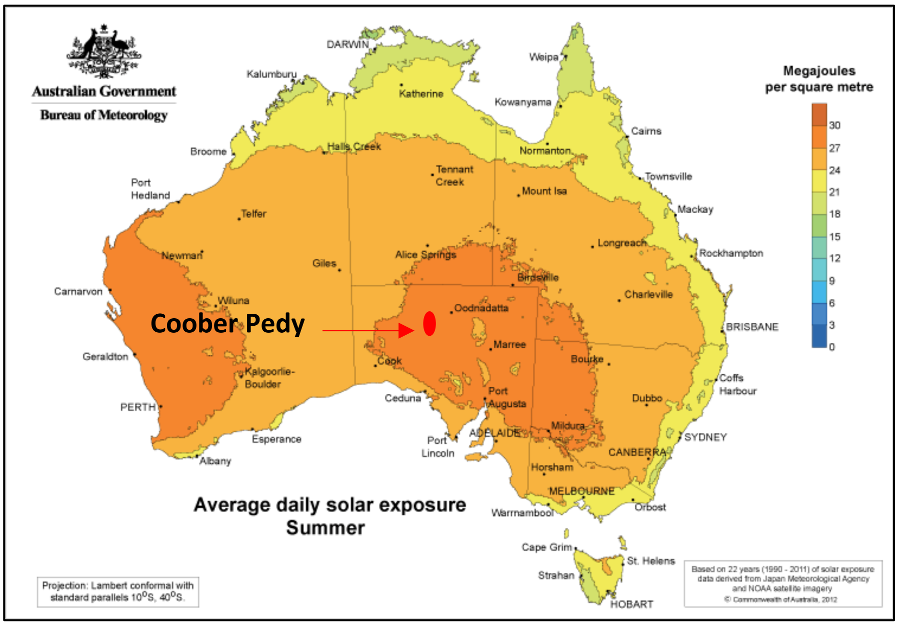


Figure 6 - Australian annual and summer Global Horizontal Irradiance, source: Australian Bureau of Meteorology

The solar irradiance at Coober Pedy has been measured using the solar modelling program PVsyst. This data is based off meteorological data collection from 1990 to 2008 and satellite information and is constantly updated to reflect the most relevant information.

Table 7 - PVSyst Global Horizontal Irradiance Output

Month	Global Horizontal irradiance (kWh/m²) (Meteo Data)	Global Horizontal irradiance (kWh/m²) (NASA satellite Data)
January	242.4	241.5
February	200.9	196.3
March	199.5	188.2
April	144.1	146.7
May	118.5	113.5
June	100	97.2
July	111.2	110.1
August	138.7	138.3
September	172.9	169.8
October	204.7	206.5
November	221.5	219.9
December	238.7	234.4
Total	2093.2	2062.1

The output from PYsyst (Table 7) showed a strong result (and correlation with NASA data) and shows excellent potential for generation, particularly in summer when the most power will be needed due to the high air conditioning power demand requirements. This is a far better source for solar generation than a project based in Melbourne which only has GHI of 1534 kW/m^2 per year.

3.1.3 Wind Energy Resource Review

The wind resource at Coober Pedy is a vital part of the new hybrid system. What makes the wind resource so valuable is the generation that it produces during the night when the sun isn't shining. The wind is strongest and most consistent at night, often providing enough energy to power the town by itself with some energy still being spilled. The data gathered at Coober Pedy is sourced from a 60m wind mast, which collects data at 10minute intervals. From historical data at this site, the average wind speed was calculated to be 7.4 m/s at 60m. Given the hub height of the turbines is 80m this needs to be adjusted to factor in the wind gradient [54].

$$v_w = v_g \left(\frac{h}{h_g}\right)^{\alpha} \qquad \text{-[1]}$$

Where h and h_g represent the height and reference height respectively, v_w and v_g represent wind speed and wind speed at reference respectively and α, the exponential which adjusts for terrain. After this adjustment the average wind speed at hub height is 7.73 m/s. This wind speed is just below the mid-point of the turbine's power curve [50], which gives quite a good yield given the variability of wind.

This variability is evident over a day, which is demonstrated by looking at the average daily wind profile over the life of the wind mast data. As was previously mentioned, the wind drops off during the day but is consistent through the night (see Figure 7). This makes the mixture of wind and solar very good for Coober Pedy as the two resources complement each other.

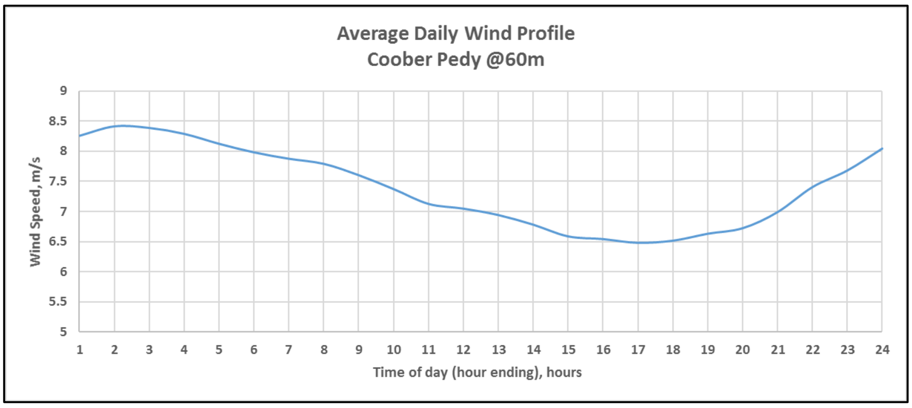


Figure 7 - Average daily wind profile at Coober Pedy on an hourly basis.

Seasonally, the wind varies slightly but it is not as defined as solar. However, there are higher wind speeds during the spring and summer months with a downturn during the autumn and winter months.

Table 8 - Average monthly wind speeds at Coober Pedy

Month	Average Wind Speed (m/s)
January	7.21
February	7.76
March	6.45
April	6.61
May	6.89
June	6.81
July	7.23
August	7.43
September	8.91
October	8.11
November	7.55
December	8.13

This does flag potential issues for the renewable only greenhouse as there is be a distinct reduction in renewable power available during the winter months. However, given historical weather data the temperature in Coober Pedy may not get cold enough to need the large amounts of energy as it does in summer.

3.1.4 Forecast Renewable Generation

3.1.4.1 Solar Generation

A number of factors have been used to forecast the generation for the renewables, based on the previous sections. The main source of data has been from a solar installation on the District Council of Coober Pedy's (DCCP) water desalination plant. This is a 80 kW array which has been generating since 2015 and has been providing high resolution generation data (10 second intervals) to EDL for 2.5 years. This information forms the basis of the generation patterns for solar on an hourly basis across the year at Coober Pedy. Over the year, this produces an average of 382.2 kWh per day which equates to a capacity factor of 19.91%. This is much lower than the expected capacity factor of the power station array of 25.45%. The reason for the difference stems from a variety of factors: tilt angle, solar module choice, O&M procedures and the size of the array. As such for the purposes of forecasting it is reasonable to assume that the predicted capacity factor is attainable and this can be calibrated once actual generation patterns are observed.

Therefore, the DCCP system has been used to form the generation pattern for a typical year, which takes into account weather events and this is scaled up to achieve the generation predicted using PVSyst irradiance data. This equates to 2.23 GWh/MW (equivalent capacity factor of 25.45%) installed of solar power per year, with the worst day happening during winter and producing 1.13 MWh and the best day producing 6.1 MWh. 'Typical' generation patterns for winter and summer (See Appendix B for full results) show the difference between the magnitude and length of the generation (Figure 8 and Figure 9).

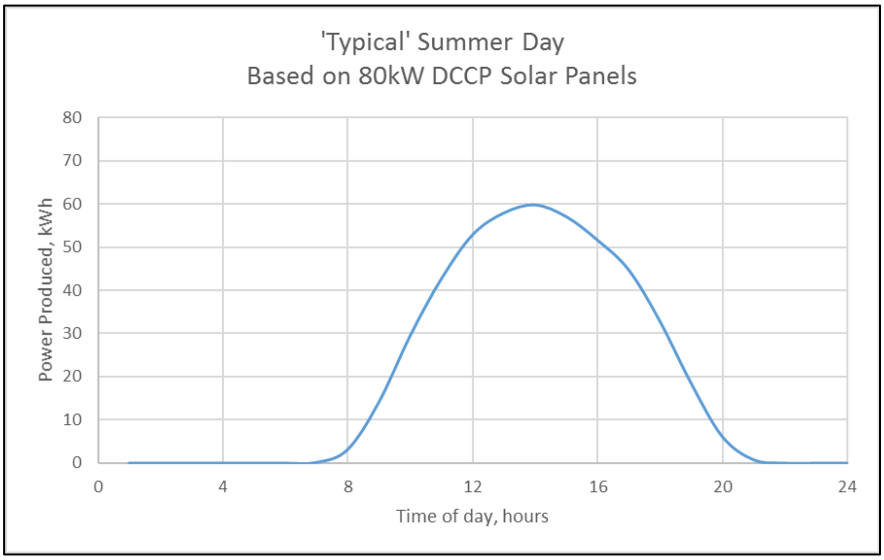


Figure 8 - Typical Summer Solar Generation Profile

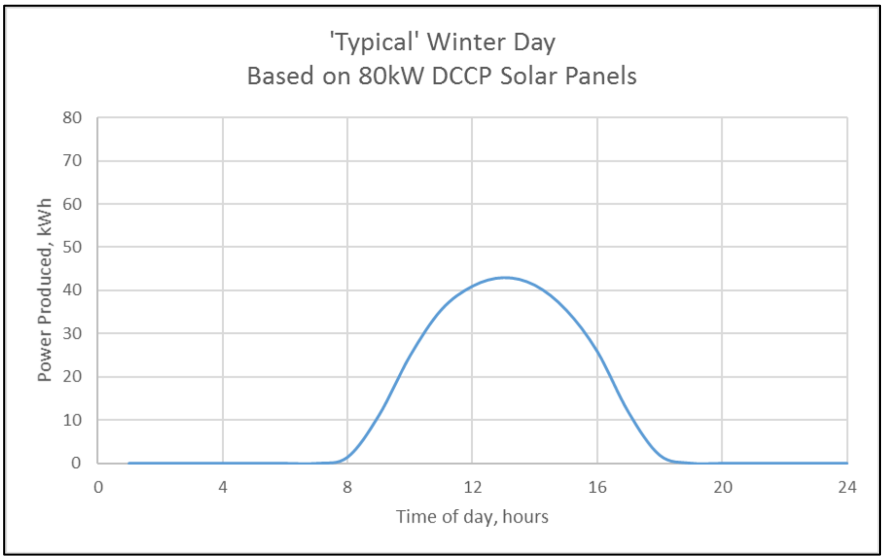


Figure 9 - Typical Winter Solar generation Profile

This again highlights potential issues with heating the greenhouse during the winter months. Given the cold will be predominantly in the night, the system will be highly reliable on wind. Fortunately in the summer months due to the high levels of solar during the hottest parts of the day, there should be an abundance of solar power, although this may be offset by higher air-conditioning needs.

3.1.4.2 Wind

From the wind perspective, the wind mast is the most accurate source of data available and has been used for the forecast year. This wind data has been extrapolated to the wind speed at 80m using equation one and then generation yield has been found using Senvion's power curve. This generation pattern was found to be far more variable during the year, the average generation over the year was 43 MWh/day, with the minimum being 2 MWh/day. This sort of day is the biggest risk to the project as this low generation effectively represents one turbine operating for an hour at capacity. The only area that spilled generation could reach the greenhouse at this stage would be from solar. It is therefore essential to determine if during these extreme low generation days the greenhouse crops could survive for a full day or more without any cooling load, or if this restricts the greenhouse too much.

Despite this, the wind at Coober Pedy is able to produce far greater amounts of energy than solar. With a capacity factor of 39.3% the station outstrips the solar component and produces 3.84 GWh/MW installed over the year. Overall it is expected that there is a total of 15.74 GWh of Wind energy produced over the year. Combined, the renewable resources are expected to produce approximately 18 GWh of energy per year.

3.2 Demand

Data for the demand was collected from internal EDL records for the past 3 years (accurate hourly data only available during this period). This is based off the volume of electricity exported from the power station. Over the measured years the average demand for the year was 11.58 GWh, making the mismatch between renewables energy generated and demand quite obvious when you compare the forecast 17.97 GWh of renewable with the average demand (6.39 GWh difference). However, a direct comparison doesn't yield the energy spilled as it doesn't take into account timing, Section 3.3 will examine this. This total demand has not altered much in recent years and shows no sign of rapid growth, with the population declining between 2006 and 2011 before slightly rising during 2011 - 2016 [55-57].

On a daily basis the demand profile exhibits quite defined peaks and troughs, with demand peaking between 7-8pm and at a low during the early morning hours of 3-5am (See Figure 10).

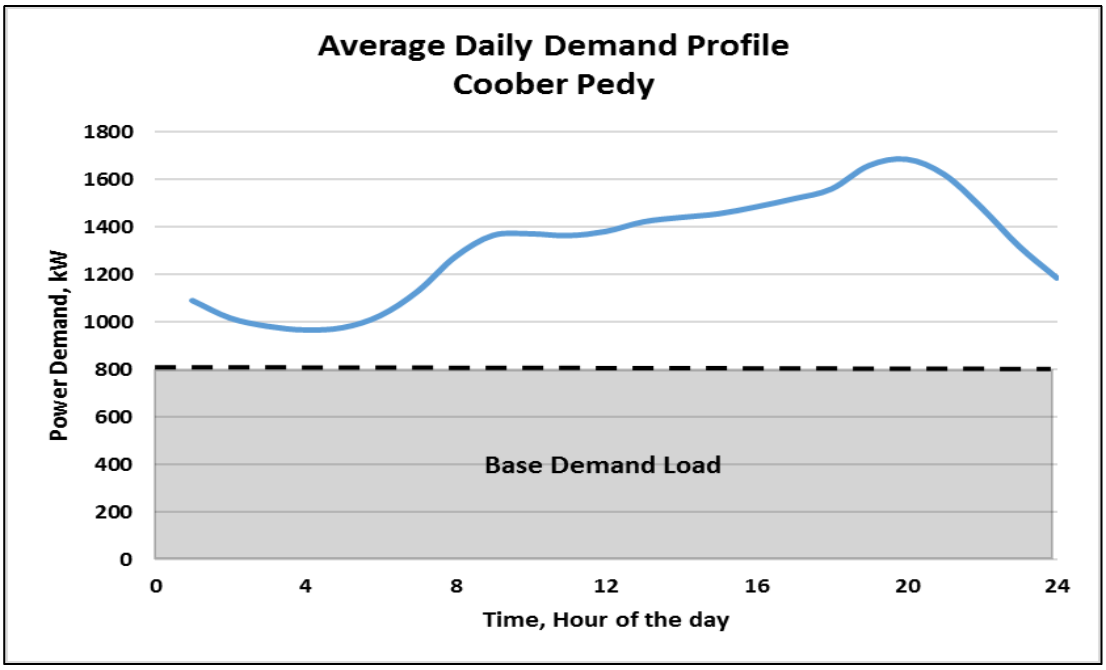


Figure 10 - Average daily demand profile at Coober Pedy

This gives a baseload of around 800 kW which during the day can be easily provided by solar the majority of the time, but during the night wind is likely to struggle to provide consistent load.

One a seasonal basis, the profile differs, with summer (Figure 11) having a very consistent increase in power use throughout the day, mirroring the temperature profile.

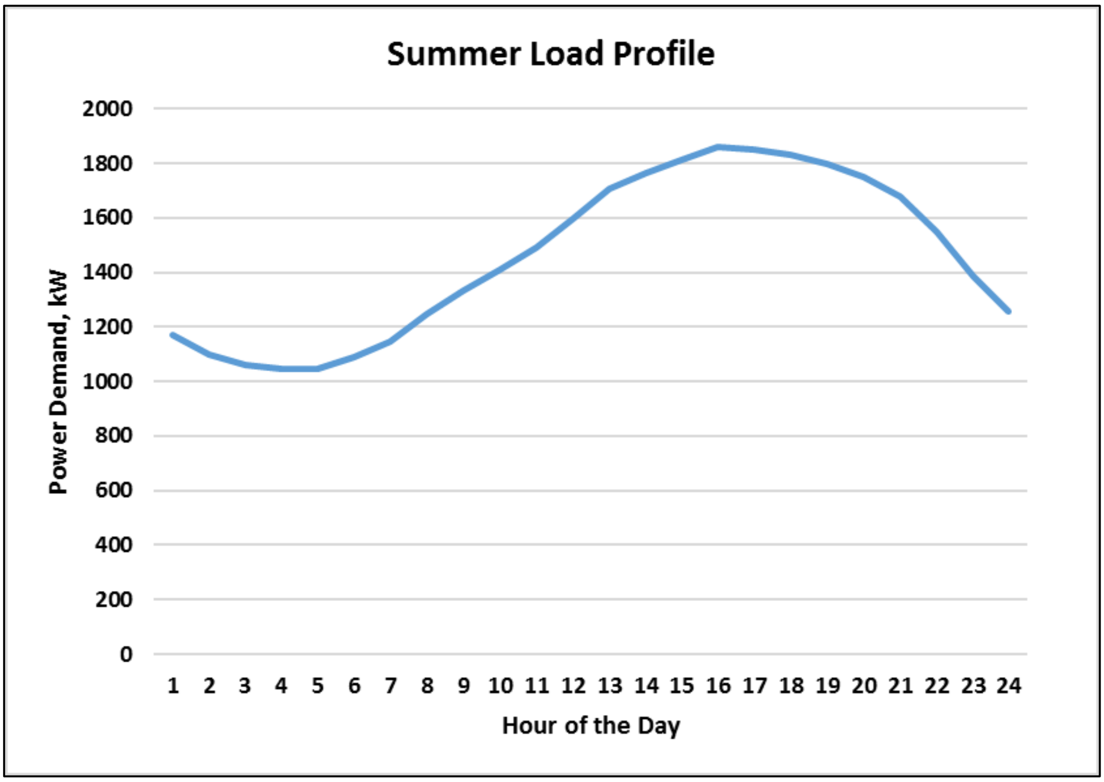


Figure 11 - Summer Load Profile at Coober Pedy

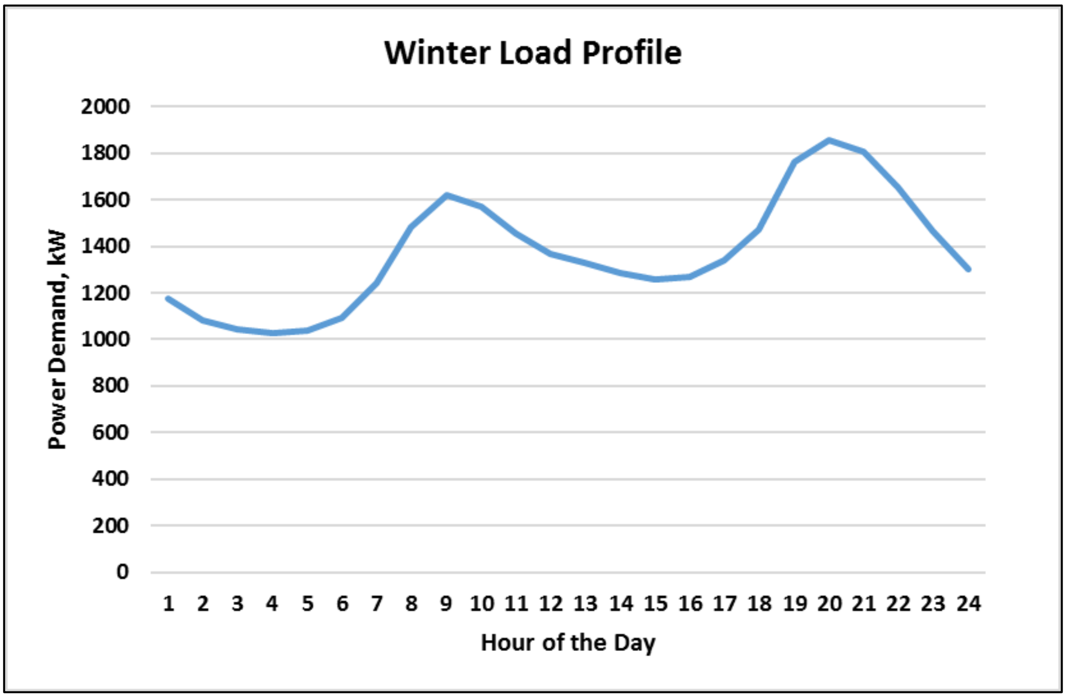


Figure 12 - Winter Load Profile at Coober Pedy

While in winter (Figure 12), the magnitude of the peak is similar, but overall less power is required with a drop in demand during the day. This makes the average daily demand 35

MWh and 33MWh for summer and winter respectively. Comparing these profiles against the renewable patterns will determine how much energy is available for use and when.

3.3 Spilled Renewable Energy Analysis

The historical demand for the years 2014 to 2016 was matched at hourly intervals against the wind and solar profiles generated by the forecasts in previous sections. The demand was the only variable in this comparison between the years, the same generation profile was applied to each of the years. It was found that there was little difference between the demand in each of the years and this is characteristic of a small rural town not undergoing high growth. This also resulted in small difference between renewable spilled in each year, with an average of 8.8 GWh of renewable energy being spilled. Over the year this means that 62.24% of the time there is renewable power available for use in the greenhouse. On the reverse side this also means a significant amount of time where there is no power available and the greenhouse must rely on the inertia of the system to get through periods of low energy. The average time without energy is 8.3 hours, with the longest period of no power happening during winter and lasting for 75 hours. The worst case scenario periods will form the basis of design of the system as the greenhouse must be able to overcome these periods for the crops to survive and grow. There are periods in summer where there is no energy for a full day and these could potentially be the greater issue compared to the long winter lull.

In terms of when the energy is available, the majority of the energy is spilled during the night when the wind is blowing strongly and there is little demand. This is depicted in Figure 13 which shows the average spilled renewable energy available per hour of the day, which has been averaged over a year of data.

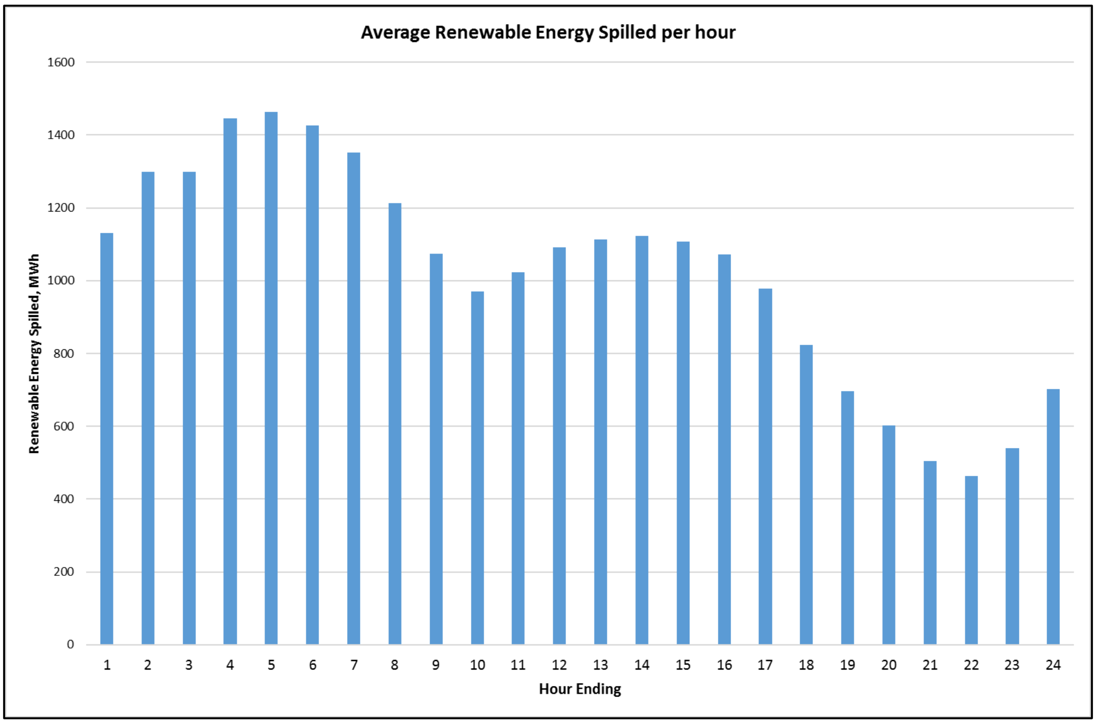


Figure 13 – Average over one year of spilled renewable electricity available at Coober Pedy on an hourly basis

This could help with the capacitance and inertia of the system, storing up energy during the early morning to use during the day when the temperature is the highest. This is especially relevant during summer, but during winter the reverse would be true with the most extreme temperatures happening at night which require the most energy to heat the system. On a seasonal basis, autumn has the lowest amount of energy available followed by winter. Summer has 10% more energy spilled than winter, with spring having the most available by a large margin. Figure 14 shows a visual comparison of the seasonal profiles.

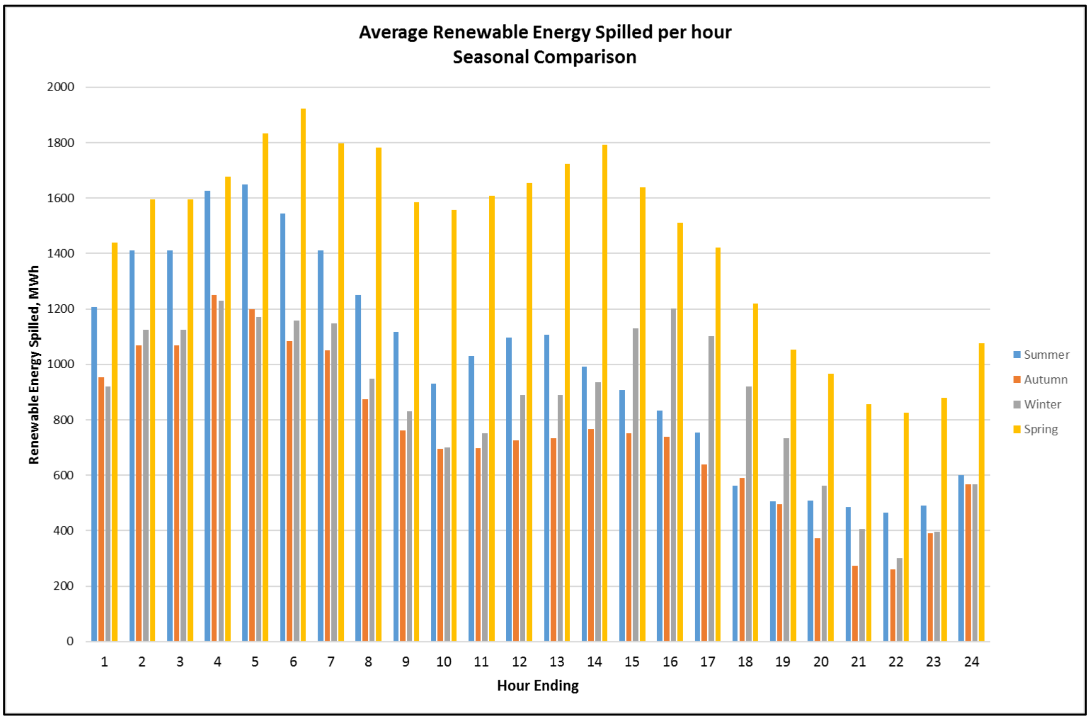


Figure 14 – Average spilled renewable electricity per season, on an hourly basis across a day.

It is clear from these profiles that the greenhouse will have to factor in some sort of energy storage through strong insulation, or heat storage. While there is an abundance of spilled energy throughout the year, the timing of when and how the energy is dispatched is the most critical element.

3.3.1 Comparison with actual data

During the writing of this thesis the commissioning and testing of the renewable-hybrid station was being undertaken. This allowed the collection of relevant electricity generation data from the site when it was available. From the period of first production on the 10th of July until the 13th of September the plant produced 252MWh of solar energy and 1,963MWh of wind energy. In comparison, during this period it was forecast in previous sections that during this timeframe 316 MWh of solar would be produced and 2,719 MWh of wind energy. This represents a 27.05% difference between forecast and actual. This is not alarming to the forecast results as it has been taken over a short period of time and during a time of testing for the system, where the systems have been shut off to allow for tuning.

If assessed individually, when looking at the solar comparing the two generation patterns are not too dissimilar. Figure 15 shows a comparison for a day where there was no testing on the solar array.

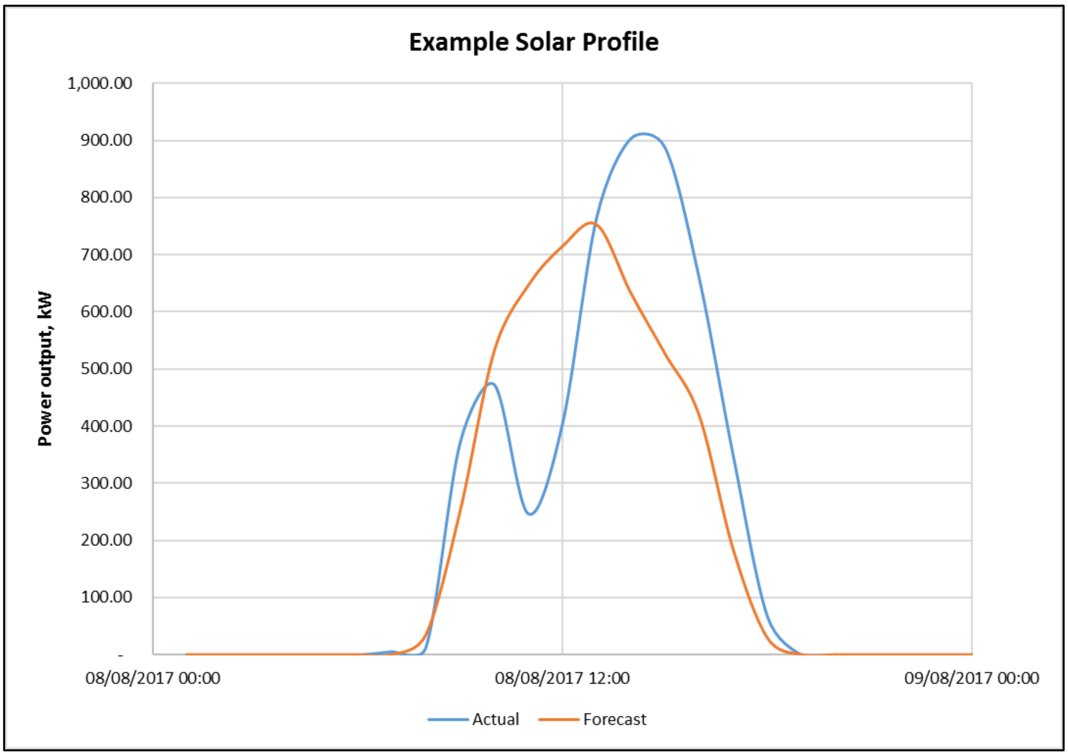


Figure 15 - Comparison solar profile between actual and forecast

As can be seen the total volume of generation is relatively similar, even if the pattern is different. Given that it is near impossible to forecast weather patterns way in advance, provided the relative volume of solar is similar then there is no reason to assume the forecast is incorrect due to inconsistent patterns. In the case of solar, the difference in the volume of generation is purely due to testing and tuning. After observing the data and comparing it with data from the bureau of meteorology, there are clearly days where there have been clear skies and no generation from the solar array. Once the power station leaves the testing and commissioning period it is expected that the solar produced will match the forecast.

When comparing the wind forecast and actuals it becomes more complex. Forecasting wind is not possible over a long timeframe as it does not have the same consistency that solar irradiance gives photovoltaic power. The most reliable method for comparing the forecast and actuals is to observe the difference in wind speeds during the period. The comparison of actuals to forecasts are shown below in Figure 16.

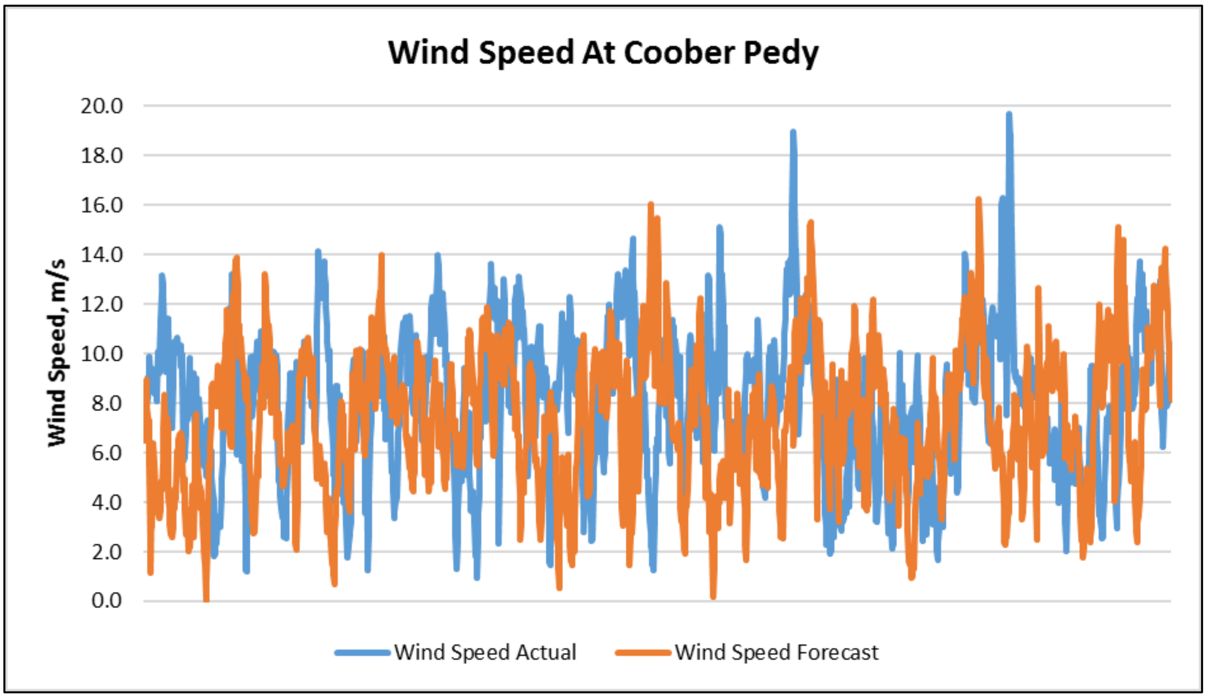


Figure 16 - Actual versus forecast wind speed comparison

The two wind profiles are relatively similar with the actual wind data being slightly higher with an average wind speed of 8.07 m/s compared to the forecast 7.4 m/s. Given the similarities in wind speed, it would mean that the difference is due to testing and potentially performance of the turbine below the stated capabilities. There is definitely some issues due to testing, as at times of high wind the turbines produce no output indicating that tuning or maintenance is being conducted. However there are periods where the wind speeds are similar between the two and the actual exported power is below the forecast. This would indicate that there is a discrepancy between the capabilities in the datasheet and the actual output, however this could also be due to the commissioning phase and should be monitored over a longer term before the changes to the forecast are made. In this instance there is enough evidence to suggest the forecast will accurately represent the wind resource available at Coober Pedy, but should be monitored for a longer period of over a year to determine whether there is a large discrepancy over power produced once testing is complete.

4.0 Greenhouse Design

The actual design and temperature modelling of the greenhouse was not included in the scope of work for this thesis. Another thesis student Ryan Harvey completed his thesis on closed greenhouses for subtropical climates and the principals and designs used in his thesis formed the basis of design for this greenhouse.

4.1 General configuration

Greenhouses are not new technology to Australia, but due to the high temperature climate the greenhouses used have been semi-closed or open greenhouses which allow higher levels of cooling through ventilation to cope with the high temperatures. This leads to a level of uncertainty surrounding the ability to control the internal temperature of the greenhouse. Closed greenhouses allow for full control over the climate by closing the windows and regulating the temperature and humidity through a cooling system. Research has shown that closed greenhouses allow for greater control of the climate leading to higher efficiencies and better crop development [58-60]. Given the high temperatures expected throughout the summer the closed greenhouse configuration was chosen to allow for full control of the internal temperature.

4.2 Greenhouse Material

For the greenhouse to be successful the correct balance of accepting and rejecting solar energy had to be chosen. Too much solar radiation and the greenhouse would overheat and not enough would cause a low yield in the plants. The greenhouse was made of glass to allow adequate sunlight in, while retaining thermal insulation. This is an issue in a subtropical climate and during high temperature periods, so to control this solar shielding was also installed. This came in the form of near infra-red Radiation reflecting films (NIR) which only removes the non-photosynthetically active component of sunlight. NIR shielding was preferred over Fresnel lenses and UV blocking films as they block sunlight without inhibiting crop yield and in some cases improving it [61-63]. This allowed for the removal of 50% of the solar radiation which was incident on the greenhouse.

4.3 Cooling System

The cooling system which was chosen for the greenhouse was an open cycle solar desiccant cooling method. This system is able to control both the temperature and humidity of the greenhouse to acceptable levels given sufficient power. This system is the main power consuming device in the greenhouse and is the focus of Ryan's thesis. The system has not been often used in scenarios exactly like this before, but have been used in similar situations and shown strong efficiency results. For further information on the modelling and design of the cooling system of the greenhouse and any other further details please refer to Ryan Harvey's '*Closed Greenhouses for Subtropical Climates*' report.

5.0 Modelling Development

5.1 Methodology

The purpose of modelling is to determine the optimal size of the greenhouse to fit the amount of spilled energy available, while maximising the profit for both the greenhouse itself and the power station. This will involve altering the greenhouse size and power supply configuration to match the spilled energy available. Maximising the spilled energy used is a priority for the power station, however it will not be chosen over a higher return for the greenhouse. As such, the financial model output will take precedent over the greenhouse's capability to run a bigger or smaller greenhouse. Because of the cost structure of the model, the biggest driving factors to determining profitability of the greenhouse is the floor space, battery size and diesel usage. To ensure profitability these two factors (battery size and diesel usage) need to be minimised.

The system was modelled from a bottom-up approach. Each model provides an output which feeds into the next model and continues through each stage until the final outcome is determined. The process flow is as follows:

1. Greenhouse sizing model

   Input(s) – Spilled renewable power available, Hourly Temperature at site and critical crop temperature range

   Output(s) – Size of battery (if required), size of greenhouse viable for power available, battery energy provided to town (if applicable), spilled energy used and diesel generation required.
2. Greenhouse financial model

   Input(s) – Size of battery and greenhouse, diesel required

   Outputs(s) – Capital requirements, project returns and project cash flows
3. Power station financial model

   Input(s) – Capital requirements, project returns, spilled energy used and cash flows

   Output(s) – Additional uplift to power station returns.

The main output is to determine the additional profit return that the greenhouse project provides to the power station. Each of the separate models is broken down in the following sections.

5.2 Greenhouse Sizing Model

5.2.1 Assumptions

The following assumptions were made when modelling the greenhouse:

- Water is easily accessible through the town water supply and will not limit crop growth.
- The solar irradiance and temperature profile remain consistent with previous data and trends.
- The greenhouse is located in close proximity to the power station and thus no power losses occur.
- Humidity is effectively controlled by the heating/cooling system and this is built into the system's power requirements model.

5.2.2 Model Development

The inputs for the model were established in section 3 of this paper, outlining the amount of irradiance, spilled energy and temperatures that could be expected over any given year. These were the key inputs into determining the amount of heat which was transferred into greenhouse at any given time. This needed to be offset by the cooling system within the greenhouse to keep the temperature between the critical range for the plant being grown. In this case the crops being grown are tomatoes which grow best under temperatures between 15 – 28°C [64, 65] with the critical temperature being 29°C and 13cC and cucumbers with temperature thresholds at 20-35°C [66, 67]. Similarly, the ideal humidity conditions for the tomatoes and cucumbers is between the ranges of 80-90% during the day and 65-75% at night [67-69]. Using these criteria as boundary conditions and the greenhouse design created by Ryan Harvey, the size of the greenhouse was determined.

Using Python 3.6 to model the system, the energy requirements of the greenhouse were determined by Ryan Harvey. The equations shown below were used to determine the amount of cooling/heating which was required:

$$Q_{in} = Q_{out}$$

$$Q_{solar} = Q_{radiation} + Q_{conduction} + Q_{desiccant} + Q_{vent}$$

$Q_{solar} = Energy\ from\ solar\ irradiance, Q_{radiation} = Energy\ lost\ from\ greenhouse\ radiation,$
$Q_{conduction} = Energy\ lost\ to\ atmosphere\ from\ conduciton,\ \ Q_{vent} = Energy\ lost\ from\ vent,$
$Q_{desiccant} = Energy\ required\ to\ heat\ or\ cool\ greenhouse$

Or

$$Q_{desiccant} = A\epsilon\sigma(T_{in}^4 - T_{out}^4) + \frac{KA(T_{in} - T_{out})}{s} + \frac{1}{2}A_v C_d \sqrt{\frac{g(T_{in} - T_{out})H_w}{2T_{out}}}\rho C_p(T_{in} - T_{out}) - Q_{solar}$$

$$A = Greenhouse\ Surface\ Area, T_{in} = Internal\ Greenhouse\ temperature,$$
$$T_{out} = External\ temperature, \epsilon = Emissivity, \sigma = Stefan - Botlz\ constant,$$
$$K = thermal\ conductivity, s = wall\ thickness, A_v = Vent\ Area, g = gravity,$$
$$H_w = Height\ of\ vent\ from\ floor, \rho = density, C_p = Specific\ heat$$

From this an energy demand profile for the year was output, which could then be used to determine the greenhouse size. This year of data represented the average conditions expected over the lifetime of the system. In the model the temperature within the greenhouse was being kept at 26.5 degrees to determine the amount of energy required. Provided that there was enough power available the temperature would always be 26.5 ^{0}C, however in the absence of this, the temperature within the greenhouse would stray and change according to the equation above. Provided the temperature stays within the critical range on a daily basis, the crops can assumed to be growing normally.

The key component for the greenhouse was ensuring that the temperatures of the greenhouse did not stray outside acceptable levels for extended periods of time. This determined the size of the battery or diesel supply needed for a given amount of floor space. The battery had to be large enough to cover periods where there is no spilled energy available. Similarly, there needed to be enough diesel capacity available (not required to power the town) when there was no spilled energy available. This meant that battery size and cost of diesel were the driving factors, with the amount of floor space possible being determined based on the acceptable limits of the greenhouse temperature.

Utilising data from Coober Pedy regarding the irradiance and temperature at the site, Ryan was able to determine a power demand curve for the year and this has been used to determine the effectiveness of power supply (See Appendix E for demand details).

Using this information the following scenarios were analysed:

Scenario 1 – Spill only, single crop, no battery, no diesel usage [Base Case]:

This was the most stringent scenario as it only allows the use of spill energy when it is available and there is no energy to call on during periods where there are shortfalls. In this scenario the temperature was set to stay constant at 26.5^{0}C. The floor space was altered until the maximum area was found which had no days outside the critical limits. It was only considered that tomatoes would be grown during this period (critical temperatures between 13-29^{0}C).

Scenario 2 – Spill only, split crop, no diesel, no battery:

As with scenario one only spill has been allowed to be used by the greenhouse with no backup. All other conditions are the same except that now two different crops are grown. Cucumber is grown during the summer months, with tomatoes being grown during the remainder of the year. This is to try and address the issues during summer by growing a higher temperature threshold crop during that period.

Scenario 3 – Spill only, no summer growing, no diesel, no battery:

This scenario removes the trouble of growing during summer, but still has the same base assumptions as the first two scenarios. In this case tomatoes have been chosen to be grown. This scenario will mean a drop in revenue but will potentially allow for a larger, more sustainable greenhouse compared to scenarios one and two.

Scenario 4 – Spill and battery, split crop, no diesel backup:

In this scenario a battery is added to the greenhouse to allow the shifting of supply around to suit the greenhouse's needs. Both the battery size and the floor size was altered to determine the optimal balance. The greenhouse was controlled to 26.5 ^{0}C and cucumbers were grown during the summer with tomatoes grown during the winter.

Scenario 5 – Spill and battery, no summer growing, no diesel backup, battery is utilised by power station during summer periods:

The final scenario blends together scenario three and four, in a bid to maximise floor area while minimising battery costs. No greenhouse production is done during the summer months and during this time the battery is used to store and distribute spilled energy to the town. The same assumptions and conditions are used as in scenario three and four. Only tomatoes are grown in this instance.

Scenario 6 – Spill with diesel backup, no battery, split crop:

Instead of a battery supplying the balancing power needs of the greenhouse, the existing diesel generators can be called upon to provide extra power to the greenhouse when needed and are available. The generators have been restricted to only have 85% of capacity available to account for the reserves required for the town demand. The temperature is still controlled to 26.5^{0}C and the size of the greenhouse floor space has been altered to find the best balance. During the summer cucumbers were grown with tomatoes being grown during the winter months.

Scenario 7 – Spill with diesel backup, no battery, no summer growing period:

This scenario is a variation on scenario 5, where it removes the need for diesel during the summer months when it is needed most, therefore reducing costs. It does not receive the same benefits of earning revenue through the use of the battery however. The same base assumptions have been used as in scenario five, only tomatoes have been grown.

Scenario 8 – Microgrid, split crop

The largest issue at Coober Pedy is the searing heat throughout the day, which can also be utilised to the greenhouse's advantage. The system still includes a battery which collects and distributes spilled power to the greenhouse. Diesel generation is also there for emergency backup purposes. This essentially forms another renewable-hybrid and creates a microgrid for the greenhouse. The temperature is still to be kept within the critical range, but at a targeted 26.5^{0}C when power is available. The split crop technique will be used for this scenario as in previous scenarios.

All of these scenarios were run through the same model and produced the same outputs to allow for accurate comparison. In these models the ability for the power station's battery system to provide power has been ignored. This battery is only used for stability and emergency purposes and so is required to be available all the time. The size of the greenhouse, size of the battery, the amount of power fed to the town by the battery and the amount of diesel used were all outputs for this model fed into the financial model.

5.3 Greenhouse Financial Model

5.3.1 Assumptions

The following assumptions were made when modelling the greenhouse:

- Greenhouse would be unaffected by potential droughts and extreme weather events.
- Construction of greenhouse would take six months with the first crops harvested in the following six month period.

- It is assumed that supply is fully met by demand and all crops grown are sold.
- It has been assumed that given the design of the greenhouse to withstand most climatic conditions the greenhouse produces crops all year round, unless otherwise stated.
- It is assumed that the costs to build a greenhouse is comparable to the research paper cited.
- There have been no major developments in greenhouse equipment in recent times which would cause a rapid decrease in costs.

5.3.2 Model Development

The major input into the greenhouse return model is the capital expenditure costs of the greenhouse and battery. In addition, the variable costs for the production of the produce is the major cost factor to consider. Both of these costs have been adjusted from a Canadian survey conducted between all the closed greenhouse operators in the state of Alberta [70]. These costs have been averaged on the basis of $CAD/m^2 across the various producers of various vegetables.

For tomato producers the cost of building the greenhouse, including equipment equates to $135.24/m^2 (CAD) of floor space. This survey was conducted in 2011 and given the industries maturity there is no reason to believe costs have drastically reduced during this time, so the costs have only been adjusted to reflect inflation and the exchange rate. This equates to $149/m^2 (AUD). For a full breakdown of the costs involved for the construction of the greenhouse from the Canadian survey see Appendix C. When compared to an Australian setting there was little to base the cost off, given that closed greenhouses are relatively non-existent. However, a recent Deloitte report on the cost of growing medicinal cannabis in Australia provides some context with the paper yielding an estimate of around $189/m^2 [71]. Given the different space and cultivation requirements (additional security and licensing needed for growing cannabis) of the two plants it is reasonable to assume that the inflation adjusted Canadian prices provide an accurate cost estimate.

When determining the capital costs of the battery the recent report by the consulting firm Lazard was used to determine the capital cost per kWh for a lithium-Ion battery for a microgrid. This equates to $954-1272/kWh after adjustment for exchange rate (based on

AUD/USD 0.79 [72]). These costs were then scaled by the size of the components (MWh of storage required and m^2 of greenhouse) as determined by the first model.

In terms of prices and variable costs, the same Canadian research paper has been used to ensure consistency across the model [70]. For tomatoes this results in an inflation adjusted price of \$118.83 of revenue/m^2 per year, with a total variable O&M cost of \$92.38/m^2. This O&M cost includes the cost of electricity and heating, so given that the greenhouse uses the spilled energy, no cost has been attributed to this. This leaves a striped back cost of \$78.49/m^2 for growing tomatoes. The cost is similar for cucumbers which yield \$118.06/m^2, with operation costs of \$75.67/m^2. These prices do not take into account the lack of supply of fresh vegetables to remote communities and the price increase that come with it [73]. For Coober Pedy, tomatoes at the local IGA cost \$6.99/kg. When comparing this to the east coast and Adelaide there is a significant price difference. The price of one kilogram of tomatoes in Adelaide, Brisbane, Melbourne and Sydney respectively is \$5.15/kg [74], \$5.49/kg [75], \$4.73/kg [76] and \$5.91/kg [77]. This gives and average price of \$5.32/kg and a difference in price between Coober Pedy and the capitals of 31.4%. As such, the price at which the vegetables produced by the greenhouse is sold has been raised by 20%. This would guarantee lower prices for the community and ensure that the supply was able to properly undercut the current supply. This leaves the revenue per square metre at \$142.6/m^2 for tomatoes and \$141.67/m^2 for cucumbers.

For the battery, a cost of \$10,000/year has been applied to account for its O&M requirements (full O&M cost breakdown can be found in Appendix D). The ability to add a royalty for the use of the spilled electricity has been included in the model, should EDL choose to enter a joint venture and not operate the greenhouse.

In terms of base finance assumptions, the project is to be fully funded via debt, assumed to be at market rates and utilising EDL's capacity to secure investment grade debt. All assets have been depreciated using straight line depreciation, with the asset having a 25 year useful life, no salvage value has been attributed to the asset. All costs are scaled to a CPI of 2.5%, which is chosen as the target inflation rate of the RBA. NPV and IRR values have been calculated using the following formula:

$$NPV = \sum_{i=1}^{n} \frac{values_i}{(1 + discount\ rate)^i}$$

$$To\ find\ IRR, NPV = 0\ and\ solve\ for\ discount\ rate$$

The discount rate used is an EDL investment hurdle rate and is consistent between the greenhouse and power station model. The purpose of this model is to determine whether the greenhouse is an investment grade project on its own without the added benefit that the power station gets. How well the power station financials stack up will determine what sort of control the EDL would take over the greenhouse. The outputs from this model, being the cash flows from the sale of goods, the amount of spilled energy used by the power station which is eligible for renewable energy certificate, the amount of diesel used and the amount if power which any battery would offset.

5.4 Power Station Financial Model

5.4.1 Assumptions

The following assumptions were made when combining the modelling of the greenhouse and power station together:

- The provision of power to the greenhouse does not put additional operational strain on the power station or reduce its efficiency to produce electricity.
- All costs to connect the greenhouse and operate it are included in the greenhouse financial model.
- The recent EDL financial model for Coober Pedy accurately incorporates the demand growth in Coober Pedy.
- There is no contract re-negotiation for the supply of electricity during the life of the asset

5.4.2 Model Development

The financial model for this was based off the financial model developed for the investment decision to install the renewable-hybrid system. Costs and revenue assumptions for the power station were based off known EDL values. Given the confidentiality of the financial model, specifics cannot be shared. The cash flows and capital costs from the greenhouse model were fed directly into this model, making only minor adjustments to the model itself.

The main benefits to the power station come from the additional use of green energy. Under the renewable energy target scheme (RET), at these levels of renewable generation capacity the station is eligible for Large Scale Certificates (LGCs) [78]. This is regardless of which funding and ownership arrangements would be taken. Depending on the agreement reached with a potential greenhouse operator would determine what other cash flows the power station received.

For this purpose three different funding arrangements were modelled:

Scenario A – EDL Builds, owns and operates the greenhouse

In this scenario EDL fully funds the capital requirements of the project, employs the staff to run it and takes all the proceeds.

Scenario B – Joint Venture with established greenhouse operator.

This scenario would see the capital requirements of the project split, with EDL to then take royalties from the greenhouse operator to pay back the capital. The greenhouse operator would bear part of the capital costs and all of the variable costs associated with running the greenhouse, including the royalties paid to EDL.

Scenario C – Project fully owned and operated by external party.

The capital requirements are fully borne by the greenhouse operator and they will purchase power from EDL to operate the plant at an agreed rate.

The results of this modelling will be discussed in the following sections.

6.0 Results and Discussion

6.1 Greenhouse Sizing Models

After completing the modelling it was clear that controlling the environment of the greenhouse in a hostile environment like Coober Pedy was quite a challenge to complete. Searing hot summer days send the internal greenhouse temperature soaring, beyond the cooling system's capabilities at certain greenhouse sizes. However, by adjusting the size and system configurations there are cases which would be deemed acceptable. The following will show the results from each scenario and outline the flaws and challenges with this endeavour.

6.1.1 Scenario 1 Results

Table 9 shows the results for the greenhouse size and configuration which best suited Scenario 1.

Table 9 - Results table for scenario 1

Factor	Value	Units
Split Crop	No	
Crop Grown	Tomatoes	
Controlled Temperature	26.5	^{0}C
Summer production	Yes	
Optimal Greenhouse Floor Size	10	m^2
Battery Size	NA	kWh
Battery Power discharged to town	NA	MWh
Diesel Used	NA	MWh
Renewable Energy consumed	4.26	MWh
Energy Shortfall	3.36	MWh
Percentage of Energy Needs Met	56.92	%
Days Above Critical Temperature	49	Days
Days Below Critical Temperature	4	Days

This was the most difficult scenario to find a configuration which would result in a successful growing period for the greenhouse. The inability to shift supply around in this model was crippling to the system during the summer periods, which is characterised by the 49 days where the average temperature inside the greenhouse exceeded the tomato's limits. This meant that there was no perfect situation where the greenhouse could successfully grow throughout the year. The resulting 10m^2 greenhouse, which was still not successful, only consumed a tiny portion of the spilled energy, approximately 0.05% (Full results can be seen in Appendix F). It is clear from this that summer is the toughest point for the greenhouse and therefore strategies were implemented to increase the size of the greenhouse.

6.1.2 Scenario 2 Results

Building from Scenario 1, Scenario 2 looked to address the issue of the summer heat by choosing a more heat resistant plant to grow during the summer and tomatoes for the remainder of the year. Table 10 shows the results for the best configuration.

Table 10 - Scenario 2 Results

Factor	Value	Units
Split Crop	Yes	
Crop 1 Grown	Cucumber	
Crop 1 Growing period	1st October – 15th March	
Crop 2 Grown	Tomatoes	
Controlled Temperature	26.5	^{0}C
Summer production	Yes	
Optimal Greenhouse Floor Size	500	m^2
Battery Size	NA	kWh
Battery Power discharged to town	NA	MWh
Diesel Used	NA	MWh
Renewable Energy consumed	205.59	MWh
Energy Shortfall	175.35	MWh
Percentage of Energy Needs Met	53.97	%
Days Above Critical Temperature	9	Days
Days Below Critical Temperature	5	Days

Introducing the more heat resistant crop for the summer months was definitely a success to increasing the size of the greenhouse and decreasing the number of days where the temperature moved outside the thresholds. What was interesting to note is that the amount of the energy needs met between Scenarios 1 and 2 decreases, but because of the shifting temperature range the temperature doesn't stray too far outside the extremes. Figure 17 shows the temperature inside the greenhouse across the year.

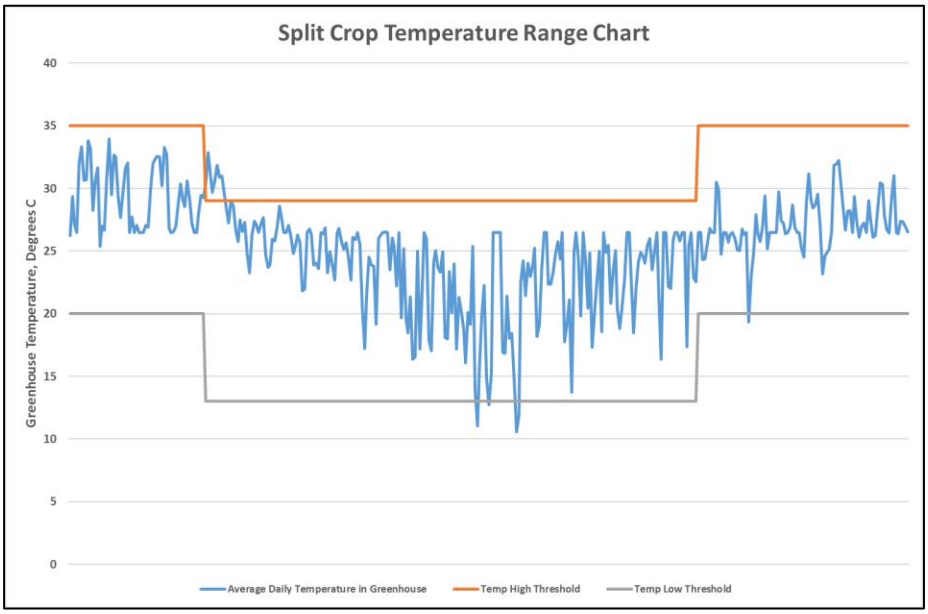


Figure 17- Temperature profile over a year for scenario 2

The temperature inside the greenhouse is rarely controlled enough for the average daily temperature to be 26.5ºC, instead the temperature floats and is pulled inside the ranges of allowable temperatures. What is also interesting about this scenario is that as the size of the greenhouse increases the number of days where the temperature exceeds the critical range does not dramatically increase, but the energy needs met percentage decreases largely. This is shown in Figure 18.

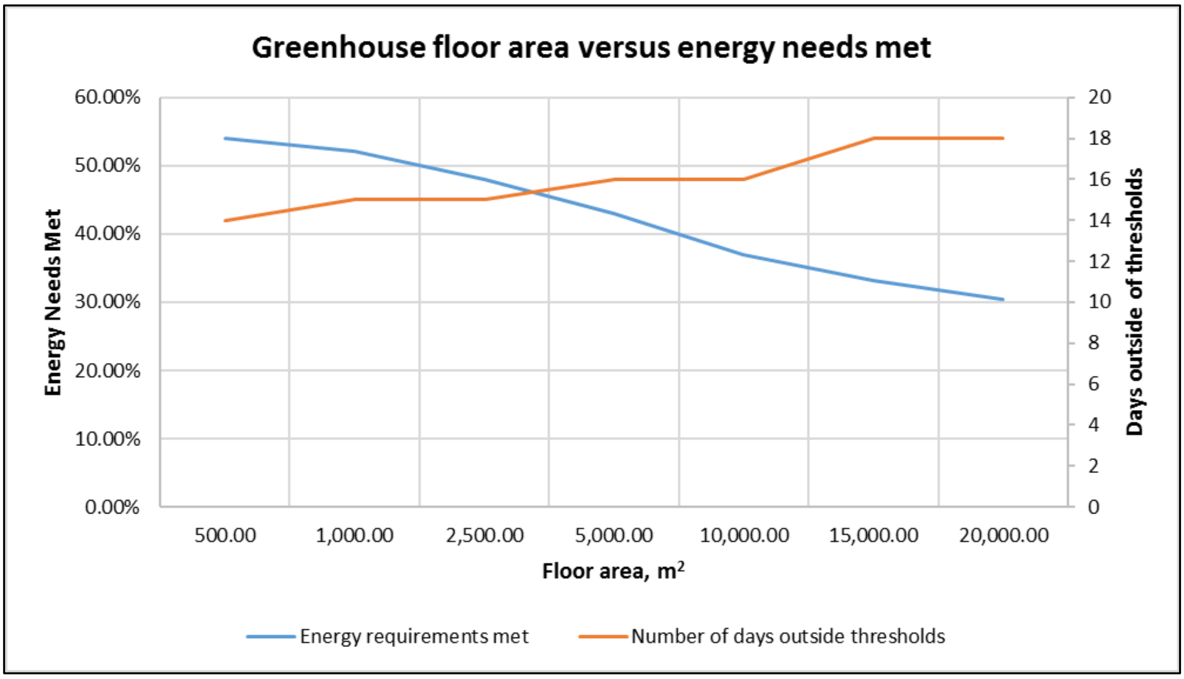


Figure 18 - Effect of increasing floor area on the energy needs met and number of days outside temperature thresholds (scenario 2)

While the greenhouse could be larger and only have a few more days outside temperature levels, it would result in over 50% of the time being without power. This could cause serious damage to the crops throughout the year due to inability to maintain the crops and therefore isn't sustainable. The main result from this scenario was the realisation that a split crop is more plausible to grow in a closed greenhouse (A full breakdown of results modelled can be found in Appendix G). The summer period should either be dealt with this way or avoided entirely.

6.1.3 Scenario 3 Results

Scenario 3 avoided the summer heat entirely rather than using different growing conditions. From October to the beginning of March the greenhouse is completely shut down and does not produce. Table 11 show the results from modelling.

Table 11 - Scenario 3 Results

Factor	Value	Units
Split Crop	No	
Crop 1 Grown	Tomatoes	
Controlled Temperature	26.5	^{0}C
Summer production	No	
Optimal Greenhouse Floor Size	500	m^2
Battery Size	NA	kWh
Battery Power discharged to town	NA	MWh
Diesel Used	NA	MWh
Renewable Energy consumed	77.24	MWh
Energy Shortfall	106.18	MWh
Percentage of Energy Needs Met	57.89	%
Days Above Critical Temperature	12	Days
Days Below Critical Temperature	4	Days

When comparing Scenario 3 to Scenario 2, the two scenarios were relatively similar in their outputs. While Scenario 3 used less energy due to most of the energy needs being required during the summer, the percentage of energy needs met is relatively similar, with only a 4% difference between the two. In addition, as the size of the greenhouse increases the energy needs met percentage decreased at a much slower rate than in scenario two (For full results modelled see Appendix H). However, despite this there are still more days outside of the temperature range than in the previous scenario. This is due purely to the lower temperature threshold of tomatoes and the slightly extended tomato growing period, which still grew during early March when the temperatures were still high. It should be noted that if cucumbers are grown as the only produce for this scenario the results are more unfavourable than for growing tomatoes. During the winter months the cucumbers are unable to grow as the temperature is regularly below 20^{0}C on average. While this configuration will provide less revenue than a split crop it cannot be yet discounted as a viable option because it does generate higher energy needs met than when growing during the summer. What was clear from the scenarios discussed is that to increase the energy needs met, there needed to be more dispatchable power available either through a battery or diesel generation.

6.1.4 Scenario 4 Results

Scenario 4 sought to address the dispatchable power through a battery system. In this scenario the size of the battery was altered as well as the size of the greenhouse. In determining the best configuration, it came down to maximising energy needs met percentage and minimising days outside the thresholds. Table 12 shows the results from the best performing configuration.

Table 12 - Scenario 4 optimal greenhouse configuration

Factor	Value	Units
Split Crop	Yes	
Crop 1 Grown	Cucumbers	
Crop 1 Growing period	1st October – 15th March	
Crop 2 Grown	Tomatoes	
Controlled Temperature	26.5	^{0}C
Summer production	Yes	
Optimal Greenhouse Floor Size	1000	m^2
Battery Size	5000	kWh
Battery Power discharged to town	NA	MWh
Diesel Used	NA	MWh
Renewable Energy consumed	733.4	MWh
Energy Shortfall	28.48	MWh
Percentage of Energy Needs Met	96.26%	%
Days Above Critical Temperature	1	Days
Days Below Critical Temperature	0	Days

With the inclusion of a battery, the greenhouse was able to better regulate when the energy is used and meet the demand. This came at the cost of a very large battery, which means a lot of capital expenditure for a small greenhouse. Increasing the size of battery increased the energy needs met percentage, a 500kWh battery with the same sized greenhouse will meet 68.01% of the energy needs of the greenhouse, but it still has 11 days where the temperature exceeds the limits. With only 1 day outside the thresholds and only 3.74% of energy needs not met, it is reasonable to assume that the crop is able to grow all year round. The difficulty will be proving that this configuration is financially viable with large costs for the battery needed for little revenue.

Another interesting result to note is how the number of days outside thresholds reaches a limit even with battery size. This is to do with extreme shortfall events, where there are days without any spill and the greenhouse is fully reliant on the battery to supply power. Unless the battery is enormous, there is no way for the greenhouse to reach 100% of the energy needs met and any battery of that size would be un-economical. Figure 19 shows the day where the temperature did exceed the limit.

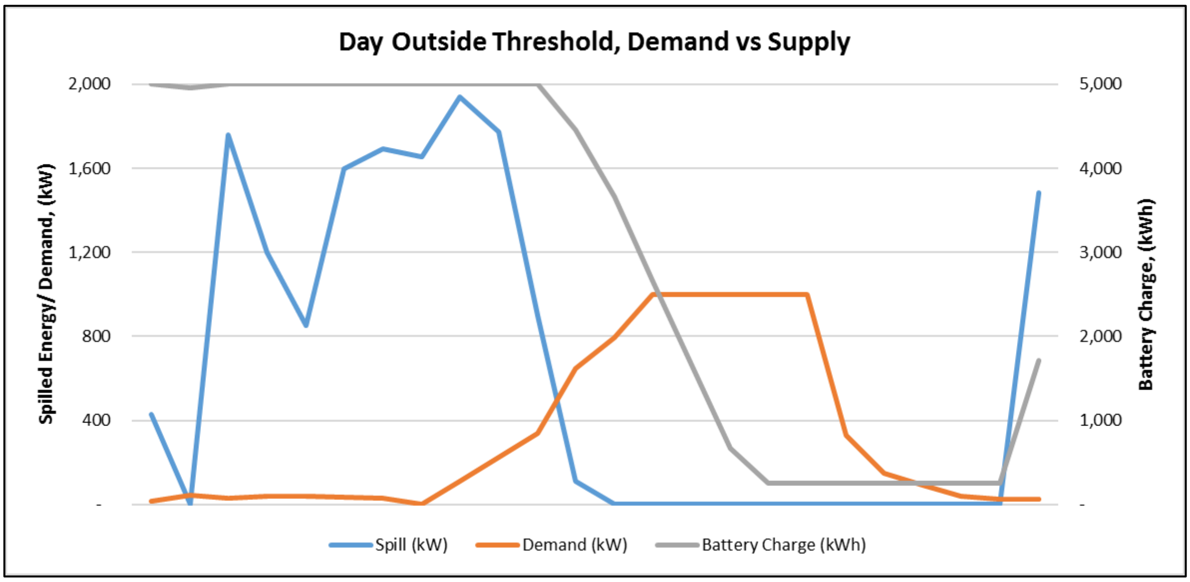


Figure 19 - Example of day which exceeds temperature thresholds despite a large battery

Spilled energy was able to meet the demand for half the day, but as that fades out, the battery must compensate. It did for a few hours, but when no spilled energy is available to support it during this time, eventually the temperature started to edge outside. This day could have been avoided with a battery double the size of the one chosen for this scenario, but that would be a 10MWh battery which is completely unreasonable (For full results see Appendix I). With these large batteries comes a large cost and with the large battery able to only support a smaller greenhouse, there needs to be a way to reduce the payback time of the battery. While this result showed that the Scenario 4 greenhouse is technically viable, it does not necessarily mean that it is economic.

6.1.5 Scenario 5 Results

Scenario 5 was a test to determine whether using a battery to feed energy back into the town when the greenhouse wasn't using it was viable. This removed the summer growing period and instead used the battery as extra supply for the town, thereby gaining revenue from power sales. The results (see Table 13) showed a similar relationship to the differences between Scenarios 2 and 3, given the same size of greenhouse and battery.

Table 13 - Results from scenario 5

Factor	Value	Units
Split Crop	No	
Crop Grown	Tomatoes	
Crop Growing period	1st March – 1st October	
Controlled Temperature	26.5	^{0}C
Summer production	No	
Optimal Greenhouse Floor Size	1000	m^2
Battery Size	5000	kWh
Battery Power discharged to town	362.52	MWh
Diesel Used	NA	MWh
Renewable Energy consumed	364.55	MWh
Energy Shortfall	2.29	MWh
Percentage of Energy Needs Met	99.37	%
Days Above Critical Temperature	1	Days
Days Below Critical Temperature	0	Days

As with Scenarios 2 and 3, there was very similar results between the split crop and no summer production method. Same amount of days outside the thresholds, but a slightly higher energy needs met percentage. The greenhouse did consume less power, but when coupled with the battery power discharged to town, it is on par with the energy consumed over the year for Scenario 4 (733.4MWh vs 727.07MWh). It is again noted that with this scenario as the size of the greenhouse increases, the energy needs met percentage declines slower than it does for the split crop scenario (Further results can be found in Appendix J). This highlights the far greater demand during summer and the potential problems with it. Both of these battery scenarios illustrate the benefits that batteries give to shifting the supply, however it has still not enabled a significant increase in greenhouse size, just an increase in technical feasibility. By adding a fully dispatchable load to the mixture, the greenhouse would be better serviced.

6.1.6 Scenario 6 Results

Using the base assumptions of Scenario 2 but including diesel into the generation mix showed a significant improvement in the performance of the greenhouse. The size of the greenhouse was able to be increased to far greater sizes without the temperatures going outside the limits. The greater control given by the diesel allowed for a greenhouse ten times the size of the ones previously tested, without huge losses in quality. Table 14 shows the results from this modelling.

Table 14 - Scenario 6 Results

Factor	Value	Units
Split Crop	Yes	
Crop 1 Grown	Cucumbers	
Crop 1 Growing period	1st October – 15th March	
Crop 2 Grown	Tomatoes	
Controlled Temperature	26.5	^0C
Summer production	Yes	
Optimal Greenhouse Floor Size	10,000	m^2
Battery Size	NA	kWh
Battery Power discharged to town	NA	MWh
Diesel Used	3,476	MWh
Renewable Energy consumed	2,811	MWh
Energy Shortfall	1,332	MWh
Renewable Penetration	45	%
Percentage of Energy Needs Met	82.52	%
Days Above Critical Temperature	2	Days
Days Below Critical Temperature	0	Days

While the energy needs met was lower than the previous two scenarios, the days above the critical temperature is relatively the same, but the size of the greenhouse has been able to be increased to an industrial scale. The two days where it is outside the range, were so marginal that they can be discounted. When observing the temperature profile (Figure 20) of the greenhouse over the year it is clear that despite the lower energy needs met, the greenhouse will still be able to function and properly grow crops.

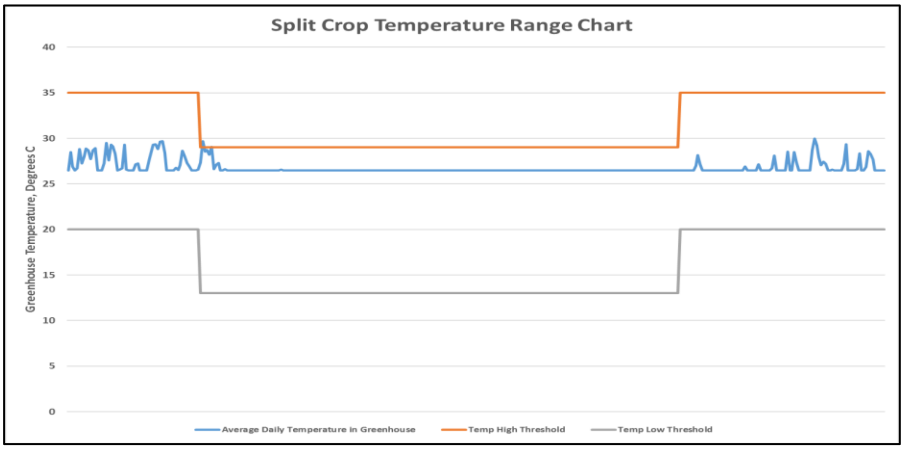


Figure 20 - Internal temperature profile of the greenhouse with diesel back up (size: 10,000m^2)

This also allowed for a greater consumption of the spilled renewable power using 2.8GWh of the spilled 8.8GWh. The trade-off is the usage of extra diesel, which raises the question of whether this defeats the purpose of the new renewable-hybrid. However, this is more of an ethical question and will not be addressed in this report. The only concern is what sort of impact that the diesel usage will have on the overall town's renewable penetration. With 45% penetration for the greenhouse and a targeted 70% penetration for the town, the greenhouse may take away from this target. Regardless of this, in terms of the success of the greenhouse this configuration showed the best results so far (Full results modelled in Appendix K).

6.1.7 Scenario 7 Results

Based off Scenario 3, this scenario included diesel generation and cut out summer growing. For the same sized greenhouse the energy needs met increased, while also decreasing diesel used and increasing renewable penetration in the greenhouse. Table 15 shows the results from modelling, further results can be found in Appendix L.

Table 15 - Scenario 7 Results

Factor	Value	Units
Split Crop	No	
Crop Grown	Tomatoes	
Crop Growing period	1st March – 1st October	

Controlled Temperature	26.5	^0C
Summer production	No	
Optimal Greenhouse Floor Size	10,000	m^2
Battery Size	NA	kWh
Battery Power discharged to town	NA	MWh
Diesel Used	1,678	MWh
Renewable Energy consumed	1,772	MWh
Energy Shortfall	218	MWh
Renewable Penetration	51	%
Percentage of Energy Needs Met	94.06	%
Days Above Critical Temperature	2	Days
Days Below Critical Temperature	0	Days

This time there was a significant difference in energy needs met by not growing in summer (11.54%). There is also a 6% increase in the renewable penetration, but this does come at the cost of a 1GWh reduction in spilled renewable energy consumed. Given the cost of diesel is high relative to other parts of Australia, this scenario could be financially superior over scenario six regardless of the lost revenue for not growing the entire year. In this scenario the days where the temperature was outside the range is also irrelevant as the growing period could easily be shifted to avoid these times. From these two scenarios, it is clear that fully dispatchable power in the form of diesel is superior to battery storage, it is able to supply more power with greater reliability. This does not discount the benefits of having a battery to increase renewable energy used, however, in order to get a lower cost outcome, the system will need to include diesel.

6.1.8 Scenario 8 Results

Combining the full assets available to create a separate microgrid for the greenhouse produced some interesting results. At the larger sizes of the greenhouse the battery was unable to add any additional energy security to the greenhouse, but rather just increased the amount of penetration of renewables. Table 16 shows the output for the optimal configuration for this scenario, further results are available in Appendix M.

Table 16 - Scenario 8 Results

Factor	Value	Units
Split Crop	Yes	

Crop 1 Grown	Cucumbers	
Crop 1 Growing period	1st October – 15th March	
Crop 2 Grown	Tomatoes	
Controlled Temperature	26.5	^{0}C
Summer production	Yes	
Optimal Greenhouse Floor Size	10,000	m^2
Battery Size	5,000	kWh
Battery Power discharged to town	NA	MWh
Diesel Used	2,484	MWh
Renewable Energy consumed	3,867	MWh
Energy Shortfall	1,268	MWh
Renewable Penetration	61	%
Percentage of Energy Needs Met	83.36	%
Days Above Critical Temperature	1	Days
Days Below Critical Temperature	0	Days

When compared to Scenario 6, the inclusion of the battery gave a 15% increase in renewable penetration. However, it does mean that a 5MWh battery is needed. Surprisingly this only added 0.84% to the energy needs met. In periods where there is large demand, there is simply no spare capacity available from the diesel engines and given the size of the greenhouse the battery is only able to cover the power needed for a short amount of time. The positive from this scenario was that there is a large portion of spilled renewable energy used, approximately 44% of the spilled renewable energy is consumed in this instance. The critical point for this scenario being preferred over the diesel only scenarios will be whether the additional use of renewable energy is able to offset the cost of the battery. Over a long period of time, with diesel costs and LGCs attributable to it, there is a chance that it may become profitable, however this will be determined in the financial modelling improved costs over time. Technically this option is viable, however like the others it will assessed on a financial basis.

6.1.9 Comparison of Scenarios – Technical feasibility

To summarise the results from the scenarios have been collated into Table 17 for easy comparison between the scenarios.

Table 17 - Comparison of scenario results

Factor	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Units
Split Crop	No	Yes	No	Yes	No	Yes	No	Yes	Nominal
Crop 1 Grown	Tomatoes	Cucumber	Tomatoes	Cucumbers	Tomatoes	Cucumbers	Tomatoes	Cucumbers	Nominal
Crop 1 Growing period	NA	1st October – 15th March	NA	1st October – 15th March	NA	1st October – 15th March	NA	1st October – 15th March	Nominal
Crop 2 Grown	NA	Tomatoes	NA	Tomatoes	NA	Tomatoes	NA	Tomatoes	Nominal
Controlled Temperature	26.5	26.5	26.5	26.5	26.5	26.5	26.5	26.5	^{0}C
Summer production	Yes	Yes	No	Yes	No	Yes	No	Yes	Nominal
Crop Growing period	NA	NA	1st March – 1st October	NA	1st March – 1st October	NA	1st March – 1st October	NA	Nominal
Optimal Greenhouse Floor Size	10	500	500	1000	1000	10,000	10,000	10,000	m^2
Battery Size	NA	NA	NA	5000	5000	NA	NA	5,000	kWh
Battery Power discharged to town	NA	NA	NA	NA	362.52	NA	NA	NA	MWh
Diesel Used	NA	NA	NA	NA	NA	3,476	1,678	2,484	MWh
Renewable Energy consumed	4.26	205.59	77.24	733.4	364.55	2,811	1,772	3,867	MWh
Energy Shortfall	3.36	175.35	106.18	28.48	2.29	1,332	218	1,268	MWh
Renewable Penetration	100	100	100	100	100	45	51	61	%
Percentage of Energy Needs Met	56.92	53.97	57.89	96.26	99.37	82.52	94.06	83.36	%
Days Above Critical Temp	49	9	12	1	1	2	2	1	Days
Days Below Critical Temp	4	5	4	0	0	0	0	0	Days

The clearest result that was determined by the modelling and is evident in Table 17 is that without a dispatchable load, there is no plausible way to run the greenhouse and still expect success. Even with changing the method of growing to a split crop and not growing during summer was not enough to reduce the burden on the greenhouse. For this reason, scenarios one, two and three were not modelled financially as they are not technically feasible. This also highlights the disparity that still exists between battery storage and base load generation like diesel. Without significant size of battery, there is no way that the storage method can match the on-demand capabilities of diesel. Without a large oversupply of renewable energy and abundance of storage (like Coober Pedy), a high-penetration renewable system will struggle to provide the same result as fossil fuel generators. This is the underlying issue with renewables and for the project to use only spilled energy it needs to be incredibly flexible with its power demands. A project that only produces a product when there was energy available would be the perfect fit for the spilled energy profile, however finding an industry that can function profitably like that will require further research.

The second interesting result was the difference between splitting the crops grown during the year and choosing not to grow during summer. By not growing in summer, the energy needs of the greenhouse are met far easier than they are for a split crop. It does halve the amount of energy that is actually used, but as a trade-off for greater crop stability it may be the better option. It also affects the amount of produce actually grown, however in the case of scenario five this may be offset by power sales. A more risk-averse owner of the greenhouse would prefer the safety of only growing for non-summer periods, but the return would likely be less than it would for taking a slightly riskier approach. There is no reason to conclude that greenhouses that grow through summer wouldn't be successful given that the majority of their energy needs are met and there are few days outside critical ranges.

In terms of the ability to control temperature, the emergence of 'extreme weather events' where there was no spilled energy available and the diesel or battery was unable to cover the loss proved to be a difficult challenge to overcome. These situations tend to happen during the summer months, during exceptionally hot days. On these days while the solar array is working excellently, the wind will die off and produce almost nothing. This leaves the diesel generators to provide additional power to the town and take away from what it provides to the greenhouse. Even with a large enough battery, this sort of event can last for hours and would require an exceptionally large battery to cover the greenhouse until diesel generation or spilled power could assist. This is shown in Figure 21.

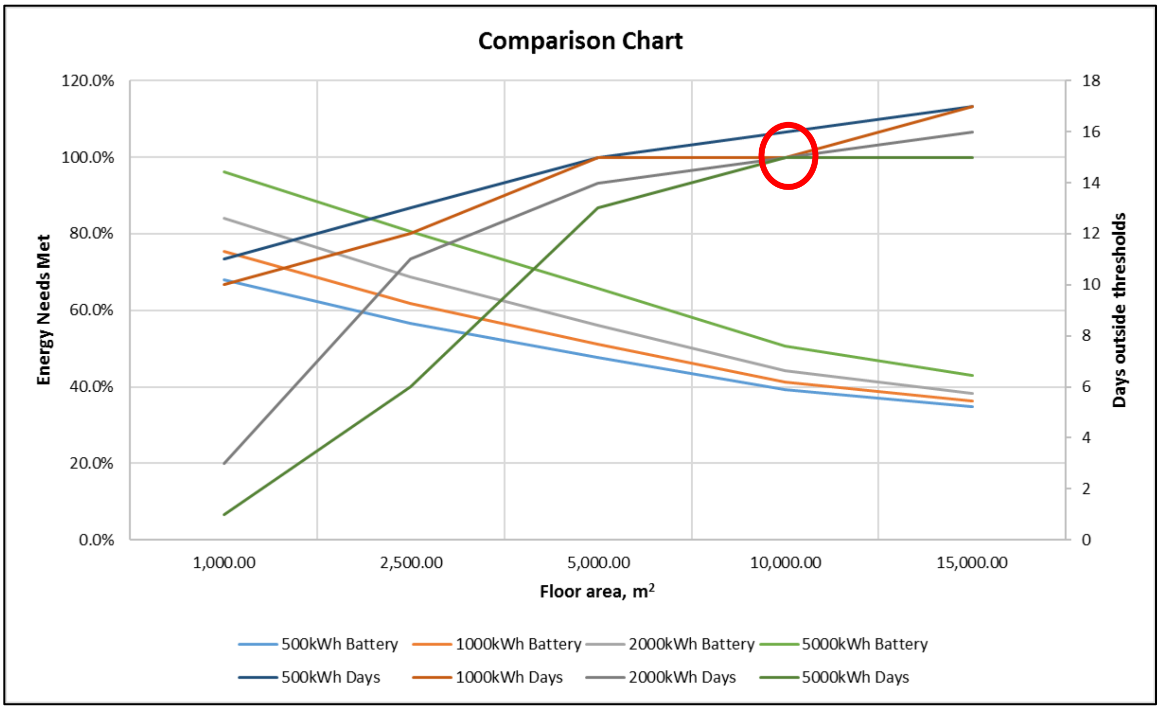


Figure 21 - Comparison of iterations of scenario 4

As is shown, at a size of 10,000m^2 even by increasing the size of the battery significantly, the greenhouse cannot get below this threshold. This makes the events unavoidable with the only solution being to increase the diesel generation capacity or to connect the greenhouse to the grid, both of which are not options explored due to the large costs involved. This solidifies the point that to use a purely spilled energy as the power source for a business, there needs to be a great deal of flexibility in production by that business.

Regardless of these underlying issues, it was deemed that Scenarios 4 to 8 were acceptable to move onto the financial modelling stage of the process.

6.2 Standalone Greenhouse Financial Modelling

The financial modelling that was undertaken was very disappointing, yielding no positive NPV projects as a standalone asset. Despite the free renewable energy supplied to the power station, the greenhouse was unable to produce high enough cash flows to overcome the high capital costs, or the high price of diesel in all cases. While the profit margin of production excluding power costs for cucumber is \$66/m^2 and \$65.86/m^2 for tomatoes (see section 5 and appendix D for more details), in order to grow the crops successfully the non-spilled energy supplied is simply too expensive.

In the case of battery storage, it is not the upkeep of the battery which is the limiting factor, but the cost of capital is too high. The best scenarios to demonstrate this were Scenarios 4 and 5 from the temperature modelling section. Table 18 shows the output from these scenarios.

Table 18 - Project Returns for scenarios four and five

Project Return Metrics	Units	Scenario 4	Scenario 5
Project NPV	$'000	(4,462)	(3,765)
Project IRR	%	0%	0%
FY19 EBITDA	$'000	18	52
FY20 EBITDA	$'000	48	127
FY21 EBITDA	$'000	49	127
FY22 EBITDA	$'000	50	128
FY23 EBITDA	$'000	51	128

While both produced positive cash flows year-on-year, over the 25 year lifespan of the equipment it was not enough to repay the initial capital expenditure of $5,149,000 ($149,000 for greenhouse, $5,000,000 for battery). While the battery allows the greenhouse to function, the levelized cost of electricity from it was far too high. For Scenario 4 this equated to $1430/MWh and $928.9/MWh for Scenario 5. Without a significant drop in the cost of capital for batteries, using batteries for this purpose where they only contribute 44% of the energy requirement is not a possibility financially. In an attempt to bring these scenarios positive, Large Generation Certificates were included for the amount of renewable energy they used. In this instance, EDL is taking ownership of the greenhouse as that is the only way the LGCs could be attributed to the greenhouse. Even with the additional LGC revenue, it was not enough to turn the projects into positive investments. It did improve the NPV's by approximately $400,000, but as the LGC scheme is likely to end in 2030 and prices will fall due to increasing amounts of renewable power, it did not have a strong enough impact. Given the inability for these scenarios to produce a positive NPV, there is no way they would be pursued and so were not modelled further.

Scenarios 6 and 8 told similar stories, and were unable to reach a positive NPV project using the base case assumptions. The limiting factor in this case was the cost of diesel generation which was $329.7/kWh (See Appendix N for conversion), based on the fuel price of $1.45/L and the generator datasheet efficiencies (see section 3.1.1.1). The output from the two configurations chosen in sections 6.1.6 and 6.1.8 are shown in Table 19.

Table 19 - Project returns for chosen configurations of scenario 6 and 8

Project Return Metrics	Units	Scenario 6	Scenario 8
Project NPV	$'000	(8,006)	(8,824)
Project IRR	%	0.0%	0.0%
FY19 EBITDA	$'000	(253)	(100)
FY20 EBITDA	$'000	(512)	(191)
FY21 EBITDA	$'000	(525)	(196)
FY22 EBITDA	$'000	(538)	(201)
FY23 EBITDA	$'000	(551)	(206)

As can be seen both scenarios were large losses and alternate configurations of the same scenarios yielded similar results (see appendix O for full results). The interesting result between these two scenarios is the difference the battery made. The extra diesel that was needed for Scenario 6 because of the lack of battery support, greatly increased the cash flow loss each period. However, because of the high capital costs of the battery, the two projects ended up yielding a similar NPV. Neither produced positive cash flows because of the cost per square metre for diesel. For Scenario 6 this was $129.8-114.6/m^2 per year and $115.8-81.9/m^2 for Scenario 8, which completely eroded the margin that the greenhouse would make otherwise (approximately $66/m^2). The addition of LGCs was again unable to produce a positive return. For these scenarios to make a positive return the diesel price needed to drop significantly or the greenhouse be connected to the grid. Using AEMO's historical data for South Australia an average grid power price of $103.91/MWh was determined and entered into the model. In this case, Scenario 6 produced a maximum positive return of 17.1%, but Scenario 8 still did not always produce a positive outcome. Only the right balances of battery size and floor size were positive NPV projects (See appendix O). However, it is highly unlikely that Coober Pedy will be connected to the grid making these configurations irrelevant for further modelling.

Scenario 7 showed improved metrics because of the removal of the summer growing period entirely. Table 20 shows the outputs from each of the greenhouse sizes.

Table 20 - Scenario seven project returns, no summer growing, varying with floor area

	Floor Area 1,000 m^2	Floor Area 2,500m^2	Floor Area 5,000m^2	Floor Area 7,500m^2	Floor Area 10,000m^2
Project NPV	(184)	(545)	(1,139)	(1,709)	(2,286)
Project IRR	0.0%	0.0%	0.0%	0.0%	0.0%
EBITDA					
FY19 EBITDA	1	(0)	(2)	(4)	(5)
FY20 EBITDA	(3)	(14)	(32)	(48)	(65)
FY21 EBITDA	(3)	(14)	(33)	(49)	(66)
FY22 EBITDA	(3)	(15)	(34)	(51)	(68)
FY23 EBITDA	(3)	(15)	(34)	(52)	(70)

Removing the summer growing period significantly reduced the energy needs of the greenhouse, given that the majority of power is needed during the hot summer months. Despite the reduction in revenue, the benefits to using less diesel across the year is a significant boost to the bottom line of the project. However, it was still not enough to produce a viable project.

The outcome from this modelling was that despite the ability to grow plants during summer, it is financially impractical due to the huge amounts of energy needed to control the temperature on 35^0C or above days. Unless the spilled energy is able to supply these needs it becomes too expensive to pay for a full diesel generator system to come online. Even after the removal of this growing period it was still economically unviable due to the high capital costs of batteries and diesel generation. Given that none of these projects could produce a positive return, the combined modelling was not undertaken.

7.0 Conclusions and Recommendations

7.1 Conclusions

The thesis has looked at ways in which spilled renewable energy could be economically utilised, with a focus on using it to operate a greenhouse in the town of Coober Pedy.

During the literature review and following interim report it was established that there were four potential ways to use the spilled energy for a useful purpose. Battery storage was discounted due to high costs of the battery and high LCOE. Hydrogen generation through electrolysis was rejected because there is a very small market for hydrogen in Australia and none in Coober Pedy. One of the promising methods that emerged from the research was demand management, to shift the load to times when renewables were strong. Unfortunately, due to the large community involvement that would be required to undertake this it was not practical to undertake this in a single year study. Constructing and operating a greenhouse was a method developed based on a similar application by a South Australian company Sundrop Farms. Given the potential to provide significant benefits to the community of Coober Pedy, through cheaper vegetables and new jobs for the town, this method was selected for investigated.

The climate, historical generation data and new power station configuration was examined to determine the amount of renewable energy which would be spilled every year. It was found that during the year renewable energy sources are expected to produce 17.97 GWh of power (solar 2.23 GWh and Wind 15.74 GWh). When compared to the town's annual demand of 11.58 GWh, it was found that 8.8 GWh (49%) was being spilled each year. In comparison with actual data from the power station, the solar array estimates were accurate, but the wind was slightly off. However, due to the plant still being in commissioning stages and the control system being adjusted, there was not enough evidence to change the forecast. It is recommended that this be monitored over a longer period of time to see how closely the forecasts and actuals match. Thus, the yearly spilled energy profile was left unchanged as originally forecast.

The greenhouse design was completed by Ryan Harvey (Thesis: *Closed Greenhouses for Subtropical Climates*) and used a desiccant cooling system to control the temperature and humidity. The greenhouse was a closed design and made of glass, which included special film to reduce the radiation coming into the greenhouse from the sun. From this design Ryan produced a power demand profile for the climate data over a year at Coober Pedy.

Using this demand profile, the technical feasibility of the greenhouse was examined by comparing the demand and the spilled energy to see whether it would effectively control the internal temperature. It was established that using only spilled energy to power the greenhouse was not technically feasible due to the intermittency issues. In order to run the greenhouse, dispatchable power was needed to supplement the intermittent spilled energy. To assist with dispatchable power battery storage and diesel generation was coupled with the greenhouse. Using different configurations it was determined that with the addition of dispatchable power the greenhouse could operate successfully technically, however they were not equal in their success. Diesel generation was able to provide better reliability and therefore sustain a larger floor area than by using a battery. Additionally, for the battery to have the same reliability as diesel the size of the battery needed to be unreasonably large (greater than 5MWh of storage).

While the scenarios with dispatchable power to supplement spilled energy were technically feasible, they did not consume as much of the spilled energy as was desirable. To match the energy required for the greenhouse to the amount of spilled energy, the floor area needed to be 11,500m^2. At this size, there is no way to use all the spilled renewable energy without having a battery that could store it all and dispatch when needed. When the size of the greenhouse was increased further so that all the spilled energy could be used, it was impossible to control the temperature or meet the energy demands. The conclusion can be drawn that while a battery and greenhouse may utilise some of the spilled energy, because the greenhouse production is independent of the spilled energy it cannot fully utilise it. For full utilisation, the industry or task that is coupled with spilled energy must be fully dependant on it to start and stop production. It also needs to be able to stop and then resume production without spoiling the product it is making.

The technically feasible scenarios were then modelled financially as a standalone asset. None of the scenarios produced a positive NPV project. This was caused by the high diesel generation costs and high capital costs of the battery. The only way that the projects produced positive returns was through assuming that the greenhouse was connected to the grid for backup rather than diesel generators. With this stipulation the scenarios which didn't involve a battery produced positive outcomes, with few scenarios involving batteries yielding positive results. However, given that Coober Pedy will not become connected to the grid, these results are not relevant to this particular scenario and so further modelling was not pursued. This may be a reality in other locations once the renewable penetration levels in Australia start to reach higher percentages, but for remote microgrids the ability to run greenhouses of spilled energy is not plausible economically unless large subsidies and drops in capital prices occur.

7.2 Recommendations

There is certainly further research which could be conducted in this space which would be of benefit to renewable-hybrid microgrids. From this particular thesis it is not recommended that a greenhouse be built and run off spilled renewable energy for the Coober Pedy microgrid. Further investigation into the following areas may produce more favourable results:

1. Research into other microgrids in other locations to determine the ideal geographical and climate conditions to build a greenhouse-renewable-diesel hybrid.
2. Investigation into alternate greenhouse designs which might improve the cooling of the greenhouse during summer.
3. Determination of how much energy is likely to be spilled should Australia reach its renewable energy targets and how this energy could be utilised.
4. Investigation into what industries could combine well with spilled energy to utilise it fully.
5. Further investigation into how and where hydrogen generation could be used in conjunction with spilled energy.
6. Given a longer time period and more resources a study on how well demand management increases renewable energy penetration and reduces spill.

While this particular scenario was not successful there are strong indications that other industries not so reliant on constant power could be enabled through the utilisation of spilled renewable energy. Additionally as the cost of storage such as batteries reduces the spilled energy could be managed to produce a more reliable and economic energy source.

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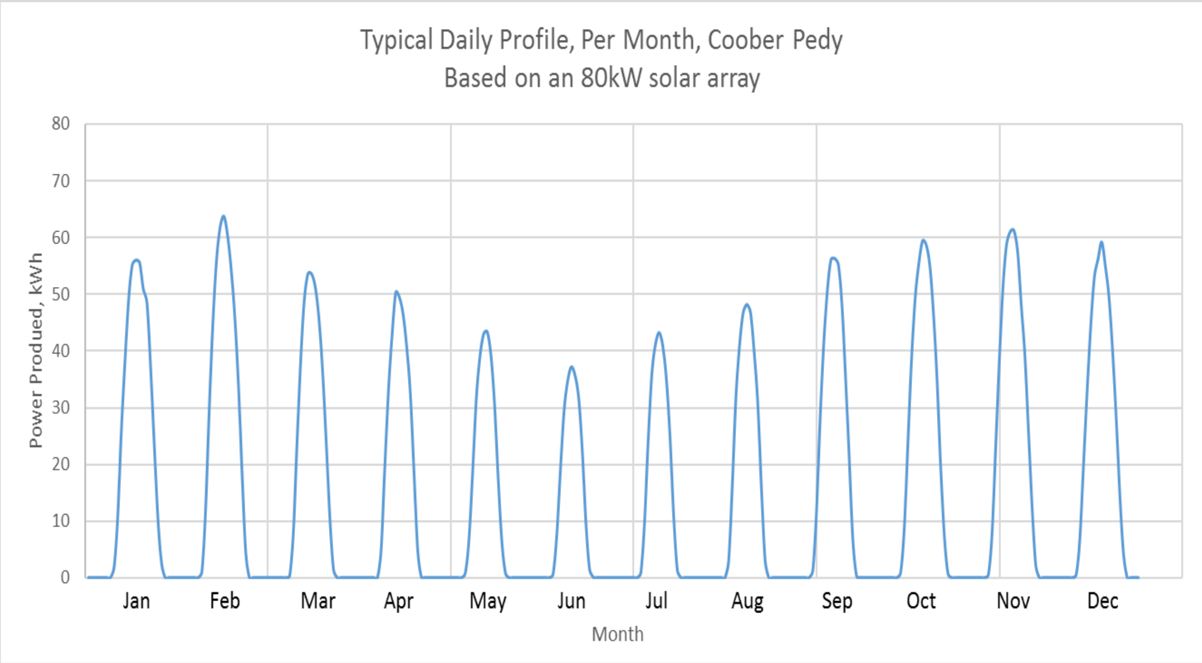
Appendix A – Coober Pedy Rainfall

Sum of Rainfall (millimetres)	Day														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
January	15.6	36	23.3	51.3	32.9	47.6	24.6	15.4	19.7	14.6	19.4	47.5	76.1	47.4	20.1
February	71.7	67.3	58.8	84.8	89.6	91.2	73.9	28.5	59.9	10.2	36.3	18.4	19.4	37	87.3
March	55.2	24	9.4	8	7.8	4.6	3.1	28	47.8	4	8.6	29.2	49.7	291.6	90.7
April	18.2	6.1	20.8	10	20.5	7.6	16.9	19.8	24.4	90.1	1	30.8	22.1	17.3	13.3
May	80.5	86	45.2	22.8	6	40.9	27.3	64.9	38.2	30.7	14	35.8	39	26.9	30
June	72.7	84.4	39.4	26	33.5	68.7	66.3	62	43.6	17	93.4	34.4	32.5	36.2	56.1
July	69.1	41.6	27.2	21.5	23.5	11.8	15.6	17.4	21.4	43.5	9.7	20.3	39	16.8	23.2
August	14.9	37.9	8.6	11.6	26.3	33.1	17.4	7.7	14.4	19.3	14	1.9	14.5	5.6	21.5
September	35	88.5	22.1	32.2	14.9	36.4	17.5	12.7	22.4	30.9	31.6	17.8	16.6	10	5.5
October	83	60.1	28.9	15.4	7.8	33	3.9	77.9	21.5	110	18.8	24.9	39.4	19.7	35.4
November	31.2	65.3	56	49.3	28	37.5	23.4	11.4	20	21.5	45.6	21.4	2.8	31.3	10.3
December	115.8	126.8	58.3	35.1	65.6	89.3	15.9	12.6	49.3	26.7	33.8	45.3	14.2	33.8	51.8
Total	662.9	724	398	368	356.4	501.7	305.8	358.3	382.6	418.5	326.2	327.7	365.3	573.6	445.2

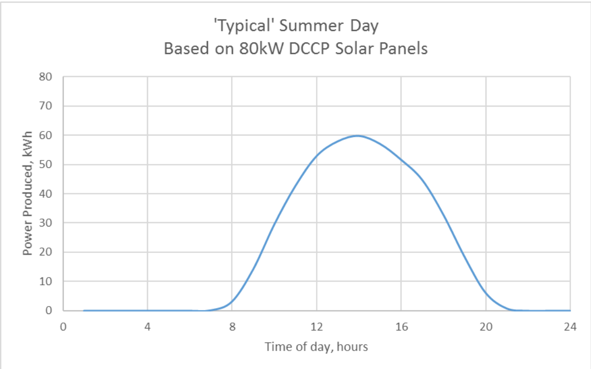
Sum of Rainfall (millimetres)	Day																Grand Total
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
January	62.6	42.3	81.9	152.2	44.6	17.1	39.8	73.1	40.7	59.6	76.4	48.3	67.1	22	44.7	38	1401.9
February	74.5	166.8	20.1	220.3	50	27.6	22.8	115.7	48.9	114.3	14.2	53.1	89.5	87.2			1939.3
March	11.6	2.6	25.6	29.4	19.6	52.8	17.9	63	47.3	40.7	29.4	8	74.5	31.9	28.1	86.8	1230.9
April	29.1	12.8	27.1	7.9	28.9	19.7	46.3	36.4	15.4	26.8	4.1	10.7	24	55	37.9		701
May	29.4	64.9	51.6	32.5	14.8	38.7	57.1	50.5	21.8	65.8	58.2	10.9	57.3	39.6	34.6	39	1254.9
June	34	21.5	30.7	20.7	58.4	48.5	46.4	47.8	0.3	20	23.7	24.9	5.3	39.7	12.5		1200.6
July	33.5	8.9	2	27.2	9.7	24.2	22.4	17.5	17.9	6.7	22.1	21	12.9	1.7	12.8	18	660.1
August	19	4.5	38.3	14.2	42.3	13.4	51.4	8.8	11.4	10.7	61.1	52.8	27.7	47.6	40.8	47	739.7
September	12.8	38.8	4	3	31.5	41.5	33.8	46.1	37.4	14.6	35.1	28.3	26.1	9.8	33		789.9
October	78.5	52.3	69.6	79.9	20.4	21.4	23.3	59.1	26.1	46.4	21.6	23.8	7.8	29.8	46.7	26.3	1212.7
November	21.9	35.1	23	114	19.1	18.8	35.9	19.8	55.2	15.5	24	83.9	38.6	29.9	34.8		1024.5
December	63.4	31	23.6	27.1	30.9	94.1	49.3	23.9	38.4	5.1	29.1	131.6	12.2	14.6	89	53.9	1491.5
Total	470.3	481.5	397.5	728.4	370.2	417.8	446.4	561.7	360.8	426.2	399	497.3	443	408.8	414.9	309	13647

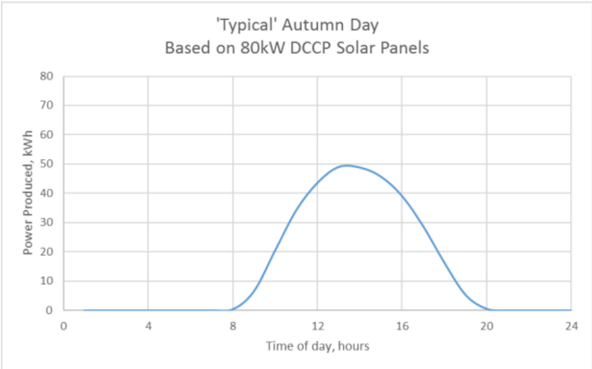
Appendix B – Typical Solar Profiles (80kW DCCP Solar Panels)

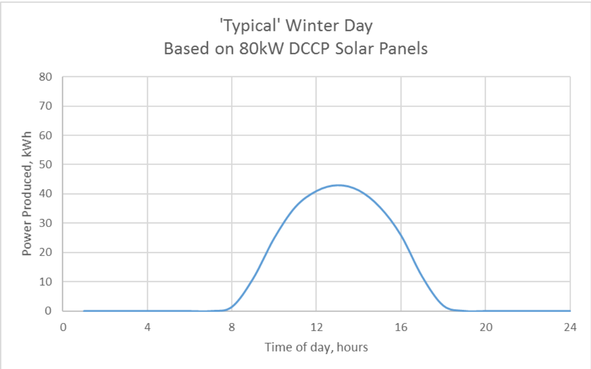
Annual

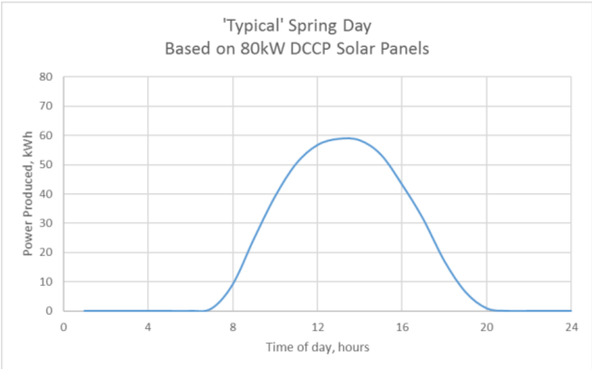


Seasonal

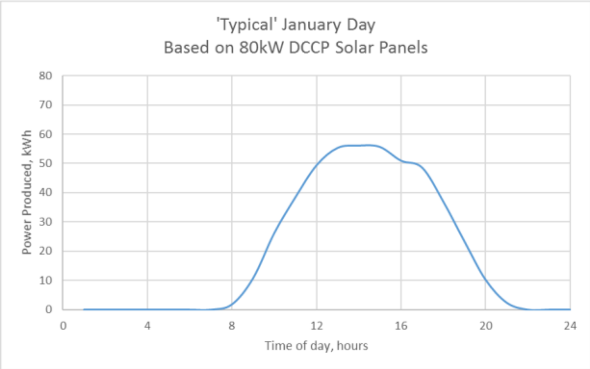


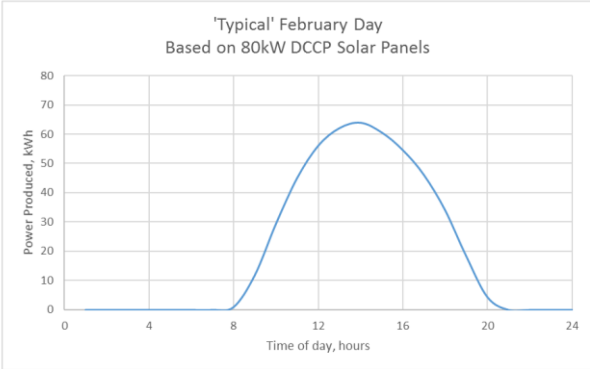






Monthly


'Typical' January Day
Based on 80kW DCCP Solar Panels
Power Produced, kWh
80 70 60 50 40 30 20 10 0
0 4 8 12 16 20 24
Time of day, hours


'Typical' February Day
Based on 80kW DCCP Solar Panels
Power Produced, kWh
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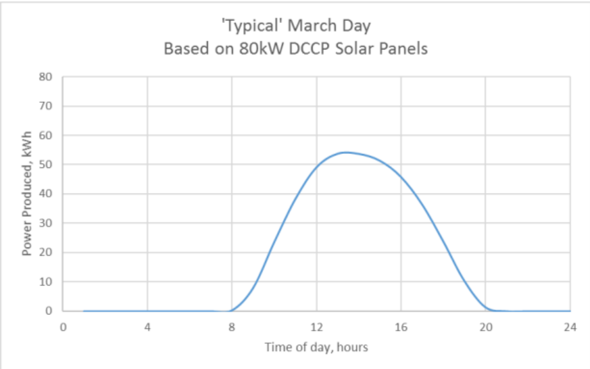
0 4 8 12 16 20 24
Time of day, hours


'Typical' March Day
Based on 80kW DCCP Solar Panels
Power Produced, kWh
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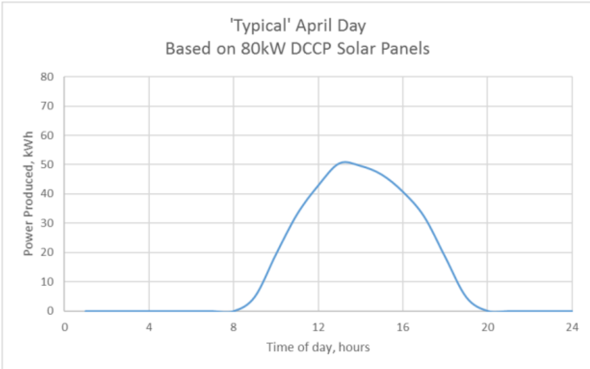
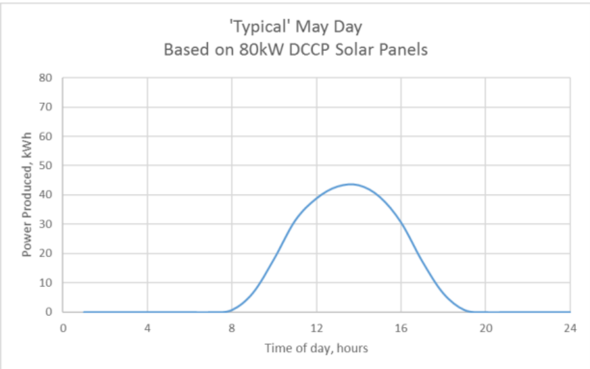
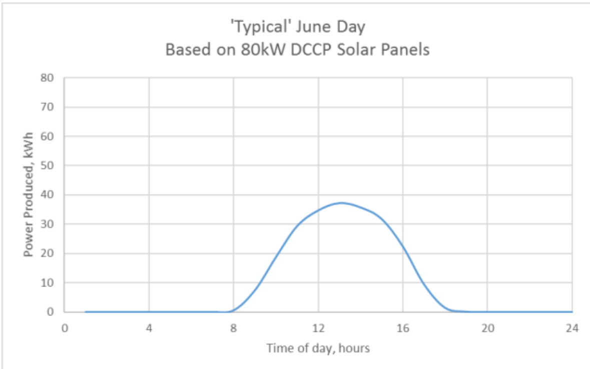
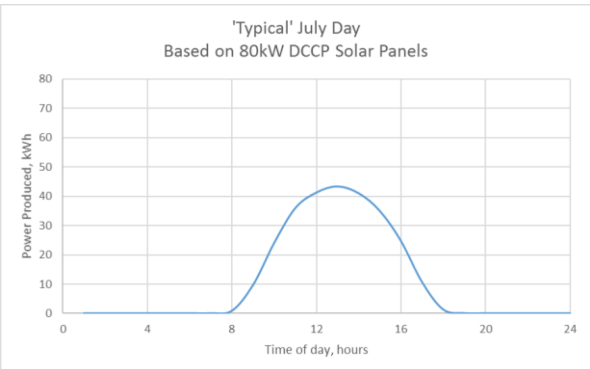
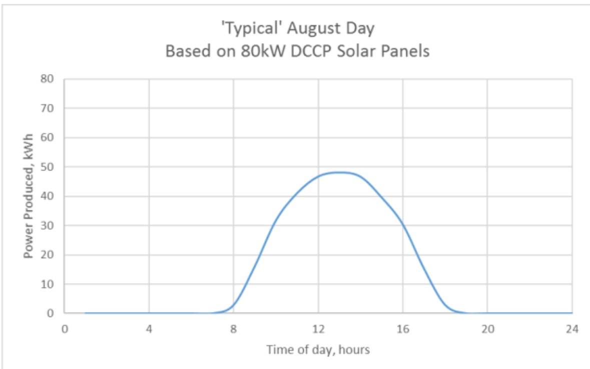
0 4 8 12 16 20 24
Time of day, hours

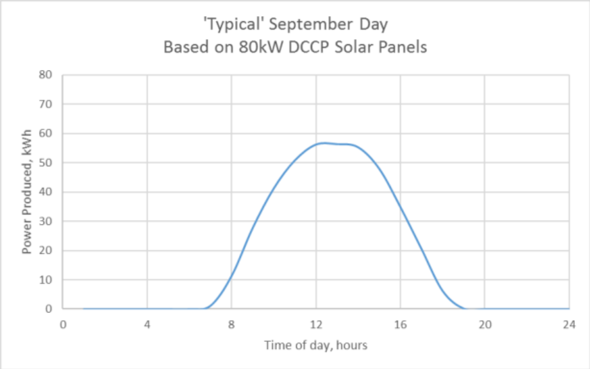

'Typical' April Day
Based on 80kW DCCP Solar Panels
Power Produced, kWh
80 70 60 50 40 30 20 10 0
0 4 8 12 16 20 24
Time of day, hours

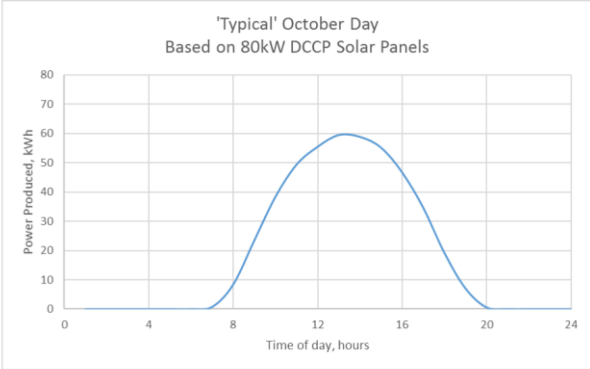

'Typical' May Day
Based on 80kW DCCP Solar Panels
Power Produced, kWh
80 70 60 50 40 30 20 10 0
0 4 8 12 16 20 24
Time of day, hours

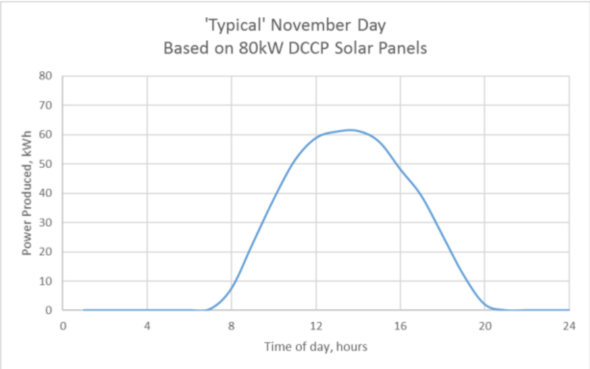

'Typical' June Day
Based on 80kW DCCP Solar Panels
Power Produced, kWh
80 70 60 50 40 30 20 10 0
0 4 8 12 16 20 24
Time of day, hours

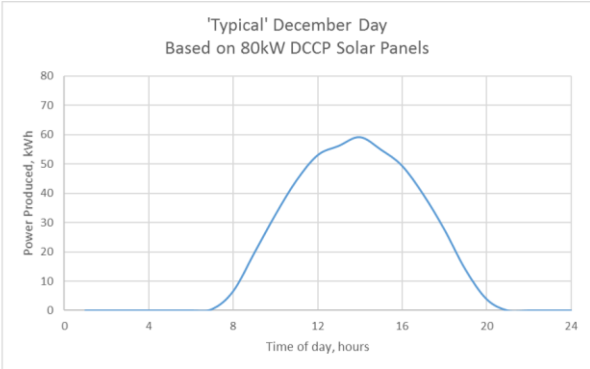

'Typical' July Day
Based on 80kW DCCP Solar Panels
Power Produced, kWh
80 70 60 50 40 30 20 10 0
0 4 8 12 16 20 24
Time of day, hours


'Typical' August Day
Based on 80kW DCCP Solar Panels
Power Produced, kWh
80 70 60 50 40 30 20 10 0
0 4 8 12 16 20 24
Time of day, hours


'Typical' September Day
Based on 80kW DCCP Solar Panels
Power Produced, kWh
Time of day, hours
0
4
8
12
16
20
24
10
20
30
40
50
60
70
80


'Typical' October Day
Based on 80kW DCCP Solar Panels
Power Produced, kWh
Time of day, hours
0
4
8
12
16
20
24
10
20
30
40
50
60
70
80


'Typical' November Day
Based on 80kW DCCP Solar Panels
Power Produced, kWh
Time of day, hours
0
4
8
12
16
20
24
10
20
30
40
50
60
70
80


'Typical' December Day
Based on 80kW DCCP Solar Panels
Power Produced, kWh
Time of day, hours
0
4
8
12
16
20
24
10
20
30
40
50
60
70
80

Appendix C – Greenhouse Capital Cost per m² for various flora

NOTE: All prices in these tables are not inflation adjusted and should be used for reference purposes only

Table 11: Average Investment for Tomato Producing Greenhouses in Alberta, 2011

Greenhouse Area: 9,043 sq. m.

INVESTMENT SUMMARY:	**Total $**	**$/sq. m.**
Land	23,689.29	2.62
Building	592,374.29	65.51
Machinery & Equipment	606,895.00	67.11
TOTAL INVESTMENT	**1,222,958.58**	**135.24**

INVESTMENT DETAIL:	**Enterprise Value ($)**	**Age (Years)**	**Depreciation ($)**
Land - Building Site:	**23,689.29**		
Greenhouse Buildings:	**592,374.29**	**10.40**	**20,733.10**
Equipment:			
Refrigeration / Freezer Storage	441.43	2.4	22.07
Warehouses / Storage Sheds	24,607.14	8.00	1,230.36
Fuel Tanks	939.29	6.40	46.96
Houses (25%)	39,589.29	33.60	1,979.46
Other Buildings	0.00	0.00	0.00
Lighting	257.14	0.90	12.86
Heating System	351,707.14	9.00	17,585.36
Ventilation System	321.43	2.00	16.07
Humidity Control	12,407.14	7.60	620.36
Benches	9,285.71	1.70	464.29
Irrigation System	16,348.57	4.60	1,634.86
Water Pumps / Sand Filters	3,932.14	8.10	393.21
Soil Mixers / Flat Fillers / Seeding Lines	0.00	0.00	0.00
Generators	10,071.43	11.10	1,007.14
Roto-Tillers	693.57	3.00	69.36
Storage / Mixing Tanks	13,214.29	9.60	1,321.43
Sterilizers	5,428.57	1.30	542.86
Sprayers	2,107.86	5.00	210.79
Carts / Dolleys	46,064.29	8.70	4,606.43
Fertilizer Injectors	6,763.57	6.70	676.36
Small Tools / Hardware	10,078.57	8.70	1,007.86
Sub-Total	**554,258.57**		**33,448.09**
Machinery & Vehicles:			
Bobcats / Forklifts	11,512.86	9.80	1,151.29
Trucks	41,123.57	10.00	4,112.36
Other Machinery	0.00	0.00	0.00
Sub-Total	**52,636.43**		**5,263.65**

Table 9: Average Investment for Cucumber Producing Greenhouses in Alberta, 2011

Greenhouse Area: 11,572 sq. m.

INVESTMENT SUMMARY:	Total $		$/sq. m.
Land	22,309.38		1.93
Building	856,625.00		74.03
Machinery & Equipment	490,735.00		42.41
TOTAL INVESTMENT	**1,369,669.38**		**118.37**

INVESTMENT DETAIL:	Enterprise Value ($)	Age (Years)	Depreciation ($)
Land - Building Site:	**22,309.38**		
Greenhouse Buildings:	**856,625.00**	**13.80**	**29,981.88**
Equipment:			
Refrigeration / Freezer Storage	985.00	2.1	49.25
Warehouses / Storage Sheds	15,125.00	9.6	756.25
Fuel Tanks	5,062.50	4.4	253.13
Houses (25%)	64,906.25	32.0	3,245.31
Other Buildings	0.00	0.0	0.00
Lighting	225.00	0.8	11.25
Heating System	262,356.25	11.6	13,117.81
Ventilation System	6,956.25	6.0	347.81
Humidity Control	16,075.00	7.0	803.75
Benches	0.00	0.0	0.00
Irrigation System	11,453.75	4.5	1,145.38
Water Pumps / Sand Filters	2,603.13	5.8	260.31
Soil Mixers / Flat Fillers / Seeding Lines	0.00	0.0	0.00
Generators	15,743.75	13.5	1,574.38
Roto-Tillers	238.75	1.8	23.88
Storage / Mixing Tanks	3,131.25	5.8	313.13
Sterilizers	31.25	0.4	3.13
Sprayers	6,976.25	7.1	697.63
Carts / Dolleys	9,316.25	9.6	931.63
Fertilizer Injectors	6,438.13	5.3	643.81
Small Tools / Hardware	14,606.25	8.3	1,460.63
Sub-Total	**442,230.01**		**25,638.47**
Machinery & Vehicles:			
Bobcats / Forklifts	11,197.50	11.30	1,119.75
Trucks	37,307.50	10.50	3,730.75
Other Machinery	0.00	0.00	0.00
Sub-Total	**48,505.00**		**4,850.50**

Table 13: Average Investment for Pepper Producing Greenhouses in Alberta, 2011

Greenhouse Area: 3,682 sq. m.

INVESTMENT SUMMARY:	Total $	$/sq. m.
Land	11,420.00	3.10
Building	361,000.00	98.05
Machinery & Equipment	172,505.00	46.85
TOTAL INVESTMENT	**544,925.00**	**148.00**

INVESTMENT DETAIL:	Enterprise Value ($)	Age (Years)	Depreciation ($)
Land - Building Site:	**11,420.00**		
Greenhouse Buildings:	**361,000.00**	**9.40**	**12,635.00**
Equipment:			
Refrigeration / Freezer Storage	406	3.4	20.3
Warehouses / Storage Sheds	19,350.00	11.20	967.50
Fuel Tanks	885.00	9.00	44.25
Houses (25%)	9,975.00	40.40	498.75
Other Buildings	0.00	0.00	0.00
Lighting	80.00	1.20	4.00
Heating System	57,260.00	8.00	2,863.00
Ventilation System	100.00	2.80	5.00
Humidity Control	2,060.00	3.80	103.00
Benches	0.00	0.00	0.00
Irrigation System	5,146.00	5.80	514.60
Water Pumps / Sand Filters	2,610.00	8.20	261.00
Soil Mixers / Flat Fillers / Seeding Lines	0.00	0.00	0.00
Generators	3,230.00	9.80	323.00
Roto-Tillers	237.00	4.20	23.70
Storage / Mixing Tanks	15,270.00	8.60	1,527.00
Sterilizers	400.00	1.80	40.00
Sprayers	647.00	6.00	64.70
Carts / Dolleys	19,362.00	9.00	1,936.20
Fertilizer Injectors	2,344.00	6.60	234.40
Small Tools / Hardware	7,630.00	9.00	763.00
Sub-Total	**146,992.00**		**10,193.40**
Machinery & Vehicles:			
Bobcats / Forklifts	6,278.00	10.80	627.80
Trucks	19,235.00	7.90	1,923.50
Other Machinery	0.00	0.00	0.00
Sub-Total	**25,513.00**		**2,551.30**

Table 15: Average Investment for Bedding Plant/Ornamental Greenhouses, 2011

Greenhouse Area: 2,076 sq. m.

INVESTMENT SUMMARY:	**Total $**	**$/sq. m.**
Land	19,017.50	9.16
Building	240,000.00	115.63
Machinery & Equipment	364,716.67	175.72
TOTAL INVESTMENT	**623,734.17**	**300.51**

INVESTMENT DETAIL:	**Enterprise Value ($)**	**Age (Years)**	**Depreciation ($)**
Land - Building Site:	**19,017.50**		
Greenhouse Buildings:	**240,000.00**	**13.30**	**8,400.00**
Equipment:			
Refrigeration / Freezer Storage	0.00	0.00	0.00
Warehouses / Storage Sheds	22,900.00	10.30	1,145.00
Fuel Tanks	1,333.33	9.20	66.67
Houses (25%)	110,416.67	19.50	5,520.83
Other Buildings	5,666.67	9.20	283.33
Lighting	333.33	1.30	16.67
Heating System	122,666.67	7.20	6,133.33
Ventilation System	2,500.00	5.20	125.00
Humidity Control	1,666.67	1.20	83.33
Benches	13,833.33	5.70	691.67
Irrigation System	7,833.33	3.50	783.33
Water Pumps / Sand Filters	6,966.67	7.00	696.67
Soil Mixers / Flat Fillers / Seeding Lines	4,166.67	6.20	416.67
Generators	8,000.00	14.80	800.00
Roto-Tillers	1,333.33	2.00	133.33
Storage / Mixing Tanks	3,283.33	4.00	328.33
Sterilizers	33.33	2.50	3.33
Sprayers	1,375.00	6.00	137.50
Carts / Dolleys	4,500.00	9.00	450.00
Fertilizer Injectors	8,400.00	8.80	840.00
Small Tools / Hardware	6041.67	9.8	604.17
Sub-Total	**333,250.00**		**19,259.16**
Machinery & Vehicles:			
Bobcats / Forklifts	8,333.33	5.00	833.33
Trucks	16,216.67	8.90	1,621.67
Other Machinery	6,916.67	0.50	691.67
Sub-Total	**31,466.67**		**3,146.67**

Table 17: Average Investment for Cut Flower Producing Greenhouses, 2011

Greenhouse Area: 3,098 sq. m.

INVESTMENT SUMMARY:	Total $	$/sq. m.
Land	12,833.33	4.14
Building	208,433.33	67.28
Machinery & Equipment	391,355.00	126.33
TOTAL INVESTMENT	**612,621.66**	**197.75**

INVESTMENT DETAIL:	Enterprise Value ($)	Age (Years)	Depreciation ($)
Land - Building Site:	**12,833.33**		
Greenhouse Buildings:	**208,433.33**	**18.70**	**7,295.17**
Equipment:			
Refrigeration / Freezer Storage	15,200.00	16.30	760.00
Warehouses / Storage Sheds	59,100.00	9.70	2,955.00
Fuel Tanks	1,500.00	15.30	75.00
Houses (25%)	80,700.00	23.70	4,035.00
Other Buildings	0.00	0.00	0.00
Lighting	4,766.67	8.70	238.33
Heating System	134,900.00	15.00	6,745.00
Ventilation System	0.00	0.00	0.00
Humidity Control	10,500.00	14.30	525.00
Benches	9,566.67	10.00	478.33
Irrigation System	10,866.67	10.00	1,086.67
Water Pumps / Sand Filters	4,166.67	11.70	416.67
Soil Mixers / Flat Fillers / Seeding Lines	2,333.33	3.30	233.33
Generators	7,233.33	22.00	723.33
Roto-Tillers	1,733.33	17.00	173.33
Storage / Mixing Tanks	5,966.67	12.70	596.67
Sterilizers	0.00	0.00	0.00
Sprayers	821.67	18.70	82.17
Carts / Dolleys	633.33	11.70	63.33
Fertilizer Injectors	3,300.00	11.70	330.00
Small Tools / Hardware	5,066.67	14.50	506.67
Sub-Total	**358,355.01**		**20,023.83**
Machinery & Vehicles:			
Bobcats / Forklifts	10,300.00	11.70	1,030.00
Trucks	22,700.00	13.30	2,270.00
Other Machinery	0.00	0.00	0.00
Sub-Total	**33,000.00**		**3,300.00**

Table 19: Average Investment for Tree Seedling Producing Greenhouses, 2011

Greenhouse Area: 11,323 sq. m.			
INVESTMENT SUMMARY:	**Total $**		**$/sq. m.**
Land	40,700.00		3.59
Building	700,760.00		61.89
Machinery & Equipment	1,291,505.00		114.06
TOTAL INVESTMENT	**2,032,965.00**		**179.54**

INVESTMENT DETAIL:	**Enterprise Value ($)**	**Age (Years)**	**Depreciation ($)**
Land - Building Site:	**40,700.00**		
Greenhouse Buildings:	**700,760.00**	**16.80**	**24,526.60**
Equipment:			
Refrigeration / Freezer Storage	29,640.00	7.00	1,482.00
Warehouses / Storage Sheds	216,400.00	16.80	10,820.00
Fuel Tanks	1,036.00	8.40	51.80
Houses (25%)	54,505.00	25.60	2,725.25
Other Buildings	0.00	0.00	0.00
Lighting	92,400.00	11.00	4,620.00
Heating System	372,840.00	14.80	18,642.00
Ventilation System	62,620.00	12.80	3,131.00
Humidity Control	50,940.00	10.40	2,547.00
Benches	106,880.00	15.00	5,344.00
Irrigation System	72,120.00	13.40	7,212.00
Water Pumps / Sand Filters	5,840.00	16.80	584.00
Soil Mixers / Flat Fillers / Seeding Lines	67,940.00	18.00	6,794.00
Generators	23,600.00	20.20	2,360.00
Roto-Tillers	0.00	0.00	0.00
Storage / Mixing Tanks	20,720.00	16.80	2,072.00
Sterilizers	7,260.00	4.20	726.00
Sprayers	2,230.00	12.20	223.00
Carts / Dolleys	18,654.00	16.00	1,865.40
Fertilizer Injectors	9,380.00	16.40	938.00
Small Tools / Hardware	10,700.00	15.60	1,070.00
Sub-Total	**1,225,705.00**		**73,207.45**
Machinery & Vehicles:			
Bobcats / Forklifts	16,260.00	15.80	1,626.00
Trucks	49,540.00	13.30	4,954.00
Other Machinery	0.00	0.00	0.00
Sub-Total	**65,800.00**		**6,580.00**

Appendix D – Greenhouse Variable Cost per m^2 for various flora

NOTE: All prices in these tables are not inflation adjusted and should be used for reference purposes only

Table 10: Production Costs and Returns for Tomato Producing Greenhouses, 2011

Production Area: 8,637 sq. m.

Number of producers: 7

			Total $	**$/sq. m.**
(A)				
	1. Crop Sales - Imputed Value of Production		931,789.71	107.88
	2. Crop Insurance Receipts		0	0.00
	3. Miscellaneous Receipts		0	0.00
	GROSS RETURN		**931,789.71**	**107.88**
(B)				
	1. Growing Media, Seed/Cuttings		53,490.00	6.19
	2. Fertilizer and Chemicals		57,110.43	6.61
	3. Greenhouse Insurance		12,984.29	1.50
	4. Trays, Boxes and Other Packaging		8,440.71	0.98
	5. Freight and/or Trucking Costs		5,323.29	0.62
	6. Auto Fuel, Repairs, Licenses and Auto Ins.		14,020.71	1.62
	7. Repairs - Buildings and Equipment		12,330.00	1.43
	8. Utilities: Natural Gas	0.00 GJ	109,981.14	12.73
	9. Electricity	0.00 KW	33,118.86	3.83
	10. Water	0.00 M^3	6,086.57	0.70
	11. Phone		1,478.86	0.17
	12. Custom Work and Specialized Labour		1,944.29	0.23
	13. Marketing Costs		136,353.57	15.79
	14. Assoc. Dues, Prof'l Fees and Promotion		9,211.00	1.07
	15. Small Tools, Supplies and Misc. Expenses		8,228.29	0.95
	16. Operating Interest Paid		852.79	0.10
	17. Labour Insurance/Benefits		23,521.57	2.72
	18. Hired Labour	16,575.14 hours	243,360.00	28.18
	19. Unpaid Labour	184.29 hours	1,474.29	0.17
	VARIABLE COSTS		**739,310.66**	**85.59**

Table 8: Production Costs and Returns for Cucumber Producing Greenhouses in Alberta, 2011

Production Area: 11,374.00 sq. m.

Number of producers: 8

			Total $	**$/sq. m.**
(A)				
	1. Crop Sales - Imputed Value of Production		1,218,848.50	107.16
	2. Crop Insurance Receipts		562.50	0.05
	3. Miscellaneous Receipts		0.00	0.00
	GROSS RETURN		**1,219,411.00**	**107.21**
(B)				
	1. Growing Media, Seed/Cuttings		131,303.25	11.54
	2. Fertilizer and Chemicals		60,927.88	5.36
	3. Greenhouse Insurance		18,599.75	1.64
	4. Trays, Boxes and Other Packaging		8,310.63	0.73
	5. Freight and/or Trucking Costs		7,437.88	0.65
	6. Auto Fuel, Repairs, Licenses and Auto Ins.		20,799.50	1.83
	7. Repairs - Buildings and Equipment		19,026.25	1.67
	8. Utilities: Natural Gas	0.00 GJ	123,307.25	10.84
	9. Electricity	0.00 KW	135,993.50	11.96
	10. Water	0.00 M^3	10,460.75	0.92
	11. Phone		3,602.13	0.32
	12. Custom Work and Specialized Labour		4,440.00	0.39
	13. Marketing Costs		151,517.88	13.32
	14. Assoc. Dues, Prof'l Fees and Promotion		4,776.81	0.42
	15. Small Tools, Supplies and Misc. Expenses		21,076.50	1.85
	16. Operating Interest Paid		1,751.19	0.15
	17. Labour Insurance/Benefits		28,035.63	2.46
	18. Hired Labour	22,277.50 hours	299,511.00	26.33
	19. Unpaid Labour	40.63 hours	325.00	0.03
	VARIABLE COSTS		**1,051,202.78**	**92.41**

Table 12: Production Costs and Returns for Pepper Producing Greenhouses, 2011

Production Area: 3,682 sq. m.
Number of producers: 5

			Total $	$/sq. m.
(A)				
	1. Crop Sales - Imputed Value of Production		381,400.00	103.59
	2. Crop Insurance Receipts		0	0.00
	3. Miscellaneous Receipts		0	0.00
	GROSS RETURN		**381,400.00**	**103.59**
(B)				
	1. Growing Media, Seed/Cuttings		40,341.80	10.96
	2. Fertilizer and Chemicals		23,571.00	6.40
	3. Greenhouse Insurance		7,746.00	2.10
	4. Trays, Boxes and Other Packaging		3,592.60	0.98
	5. Freight and/or Trucking Costs		5,071.00	1.38
	6. Auto Fuel, Repairs, Licenses and Auto Ins.		5,753.80	1.56
	7. Repairs - Buildings and Equipment		10,856.00	2.95
	8. Utilities: Natural Gas	0.00 GJ	38,107.40	10.35
	9. Electricity	0.00 KW	51,983.60	14.12
	10. Water	0.00 M^3	945.00	0.26
	11. Phone		933.00	0.25
	12. Custom Work and Specialized Labour		1,490.00	0.40
	13. Marketing Costs		36,110.00	9.81
	14. Assoc. Dues, Prof'l Fees and Promotion		2,537.00	0.69
	15. Small Tools, Supplies and Misc. Expenses		9,464.40	2.57
	16. Operating Interest Paid		778.20	0.21
	17. Labour Insurance/Benefits		1,932.00	0.52
	18. Hired Labour	8,554.40 hours	114,073.00	30.98
	19. Unpaid Labour	317 hours	2,536.00	0.69
	VARIABLE COSTS		**357,821.80**	**97.18**

Table 14: Production Costs and Returns for Bedding Plant/Ornamental Greenhouses, 2011

Production Area: 2,076 sq. m.
Number of producers: 8

			Total $	**$/sq. m.**
(A)				
	1. Crop Sales - Imputed Value of Production		319,666.67	154.01
	2. Crop Insurance Receipts		9,333.33	4.50
	3. Miscellaneous Receipts		0.00	0.00
	GROSS RETURN		**329,000.00**	**158.51**
(B)				
	1. Growing Media, Seed/Cuttings		40,750.00	19.63
	2. Fertilizer and Chemicals		3,466.67	1.67
	3. Greenhouse Insurance		3,833.33	1.85
	4. Trays, Boxes and Other Packaging		8,425.00	4.06
	5. Freight and/or Trucking Costs		4,966.67	2.39
	6. Auto Fuel, Repairs, Licenses and Auto Ins.		5,641.67	2.72
	7. Repairs - Buildings and Equipment		3,933.33	1.89
	8. Utilities: Natural Gas		15,830.50	7.29
	9. Electricity	0.00 GJ	6,304.88	2.90
	10. Water	0.00 KW	853.13	0.39
	11. Phone	0.00 M^3	1,621.67	0.78
	12. Custom Work and Specialized Labour		250.00	0.12
	13. Marketing Costs		1,733.33	0.83
	14. Assoc. Dues, Prof'l Fees and Promotion		11,750.00	5.66
	15. Small Tools, Supplies and Misc. Expenses		3,141.67	1.51
	16. Operating Interest Paid		1,416.67	0.68
	17. Labour Insurance/Benefits		4,933.33	2.38
	18. Hired Labour	9,680.83 hours	104,626.67	50.40
	19. Unpaid Labour	363.33 hours	2,906.67	1.40
	VARIABLE COSTS		**225,013.35**	**108.39**

Table 16: Production Costs and Returns for Cut Flower Producing Greenhouses, 2011

Production Area: 2,994 sq. m.
Number of producers: 3

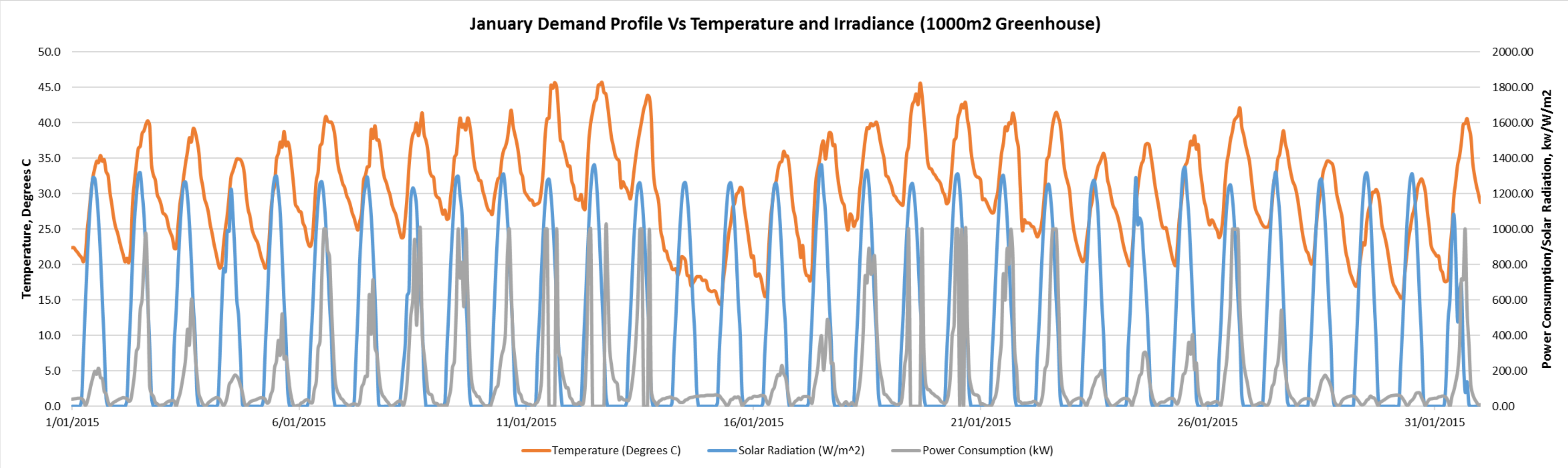
			Total $	$/sq. m.
(A)				
	1. Crop Sales - Imputed Value of Production		446,600.00	149.16
	2. Crop Insurance Receipts		0	0.00
	3. Miscellaneous Receipts		7,333.33	2.45
	GROSS RETURN		**453,933.33**	**151.61**
(B)				
	1. Growing Media, Seed/Cuttings		28,884.00	9.65
	2. Fertilizer and Chemicals		11,867.33	3.96
	3. Greenhouse Insurance		7,106.00	2.37
	4. Trays, Boxes and Other Packaging		9,014.33	3.01
	5. Freight and/or Trucking Costs		23,245.00	7.76
	6. Auto Fuel, Repairs, Licenses and Auto Ins.		12,500.00	4.18
	7. Repairs - Buildings and Equipment		11,159.00	3.73
	8. Utilities: Natural Gas	0.00 GJ	33,997.33	11.36
	9. Electricity	0.00 KW	33,836.67	11.30
	10. Water	0.00 M^3	123.33	0.04
	11. Phone		4,025.67	1.34
	12. Custom Work and Specialized Labour		254.33	0.08
	13. Marketing Costs		700.00	0.23
	14. Assoc. Dues, Prof'l Fees and Promotion		13,072.33	4.37
	15. Small Tools, Supplies and Misc. Expenses		5,713.33	1.91
	16. Operating Interest Paid		500.00	0.17
	17. Labour Insurance/Benefits		3,512.00	1.17
	18. Hired Labour	8,196.00 hours	96,626.67	32.27
	19. Unpaid Labour	3,070.00 hours	24,560.00	8.20
	VARIABLE COSTS		**320,697.32**	**107.11**

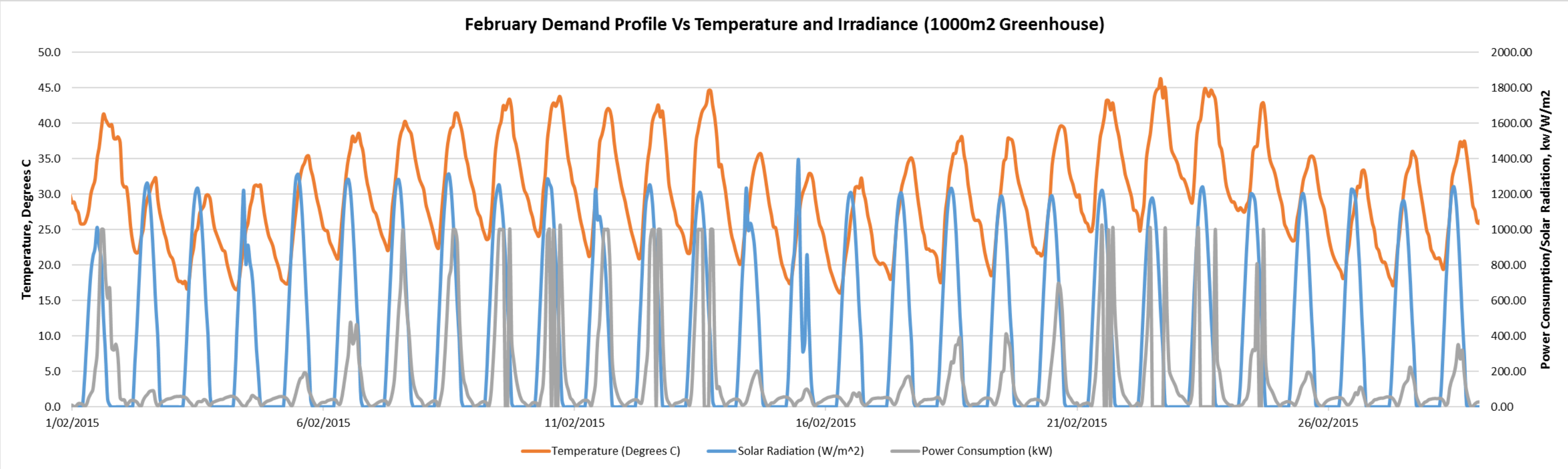
Table 18: Production Costs and Returns for Tree Seedling Producing Greenhouses, 2011

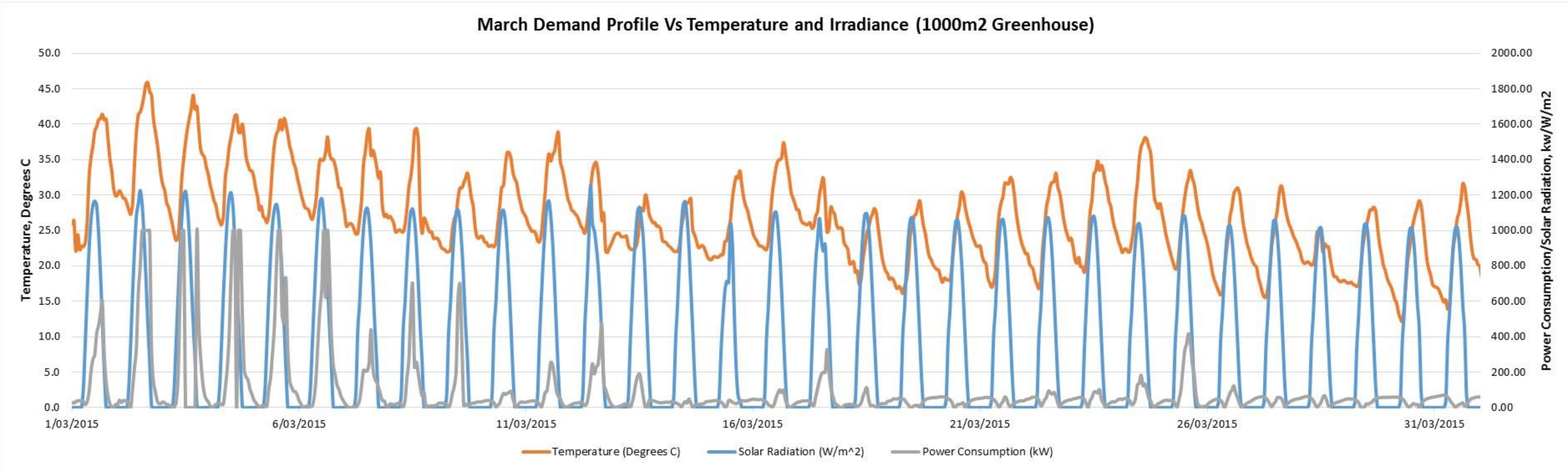
Production Area: 10,569 sq. m.
Number of producers: 5

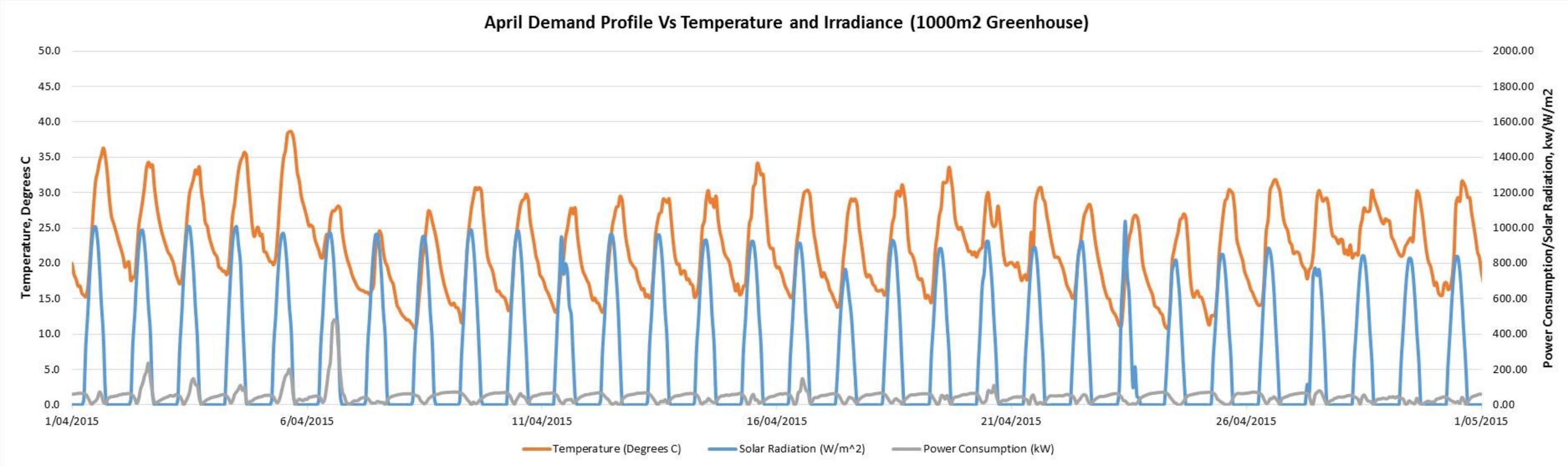
			Total $	$/sq. m.
(A)				
	1. Crop Sales - Imputed Value of Production		1,074,348.60	101.65
	2. Crop Insurance Receipts		0	0.00
	3. Miscellaneous Receipts		0.00	0.00
	GROSS RETURN		**1,074,348.60**	**101.65**
(B)				
	1. Growing Media, Seed/Cuttings		43,464.00	4.11
	2. Fertilizer and Chemicals		18,587.40	1.76
	3. Greenhouse Insurance		21,030.00	1.99
	4. Trays, Boxes and Other Packaging		96,490.00	9.13
	5. Freight and/or Trucking Costs		5,646.00	0.53
	6. Auto Fuel, Repairs, Licenses and Auto Ins.		8,080.00	0.76
	7. Repairs - Buildings and Equipment		39,680.00	3.75
	8. Utilities: Natural Gas	0.00 GJ	126,480.00	11.97
	9. Electricity	0.00 KW	49,204.00	4.66
	10. Water	0.00 M^3	3,706.00	0.35
	11. Phone		4,244.00	0.40
	12. Custom Work and Specialized Labour		3,542.00	0.34
	13. Marketing Costs		82,100.00	7.77
	14. Assoc. Dues, Prof'l Fees and Promotion		11,910.00	1.13
	15. Small Tools, Supplies and Misc. Expenses		5,080.00	0.48
	16. Operating Interest Paid		9,400.00	0.89
	17. Labour Insurance/Benefits		15,900.00	1.50
	18. Hired Labour	25,925.40 hours	330,581.27	31.28
	19. Unpaid Labour	3,690.00 hours	37,470.00	3.55
	VARIABLE COSTS		**912,594.67**	**86.35**

Appendix E – Demand Profile of the Greenhouse

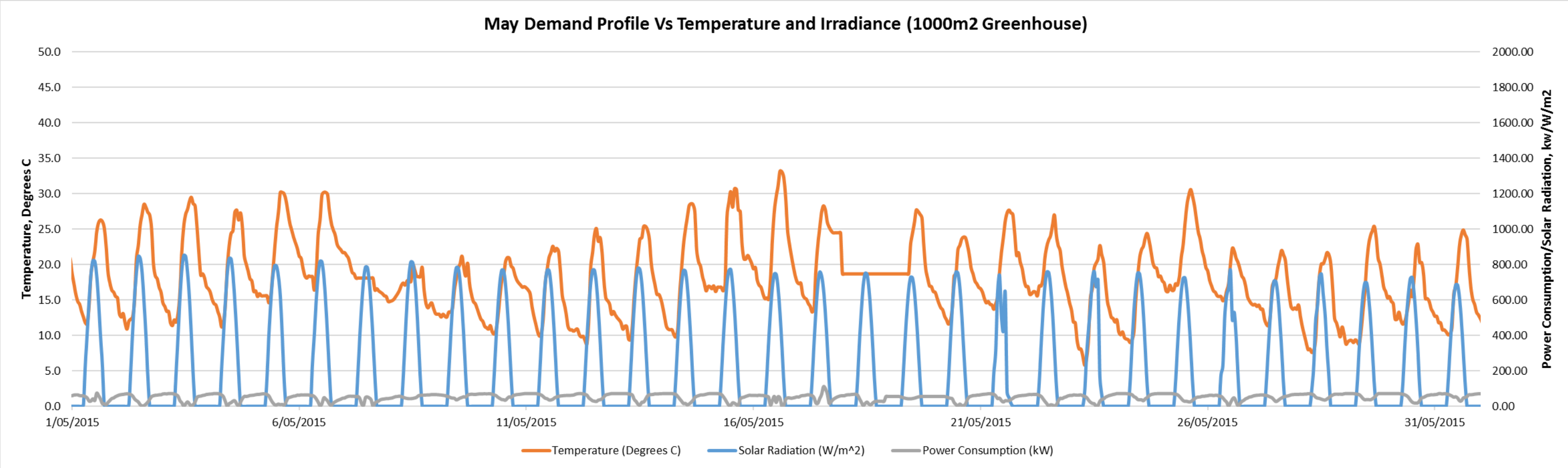



February Demand Profile Vs Temperature and Irradiance (1000m2 Greenhouse)
Temperature, Degrees C
Power Consumption/Solar Radiation, kw/W/m2
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
2000.00
1800.00
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
1/02/2015
6/02/2015
11/02/2015
16/02/2015
21/02/2015
26/02/2015
Temperature (Degrees C)
Solar Radiation (W/m^2)
Power Consumption (kW)

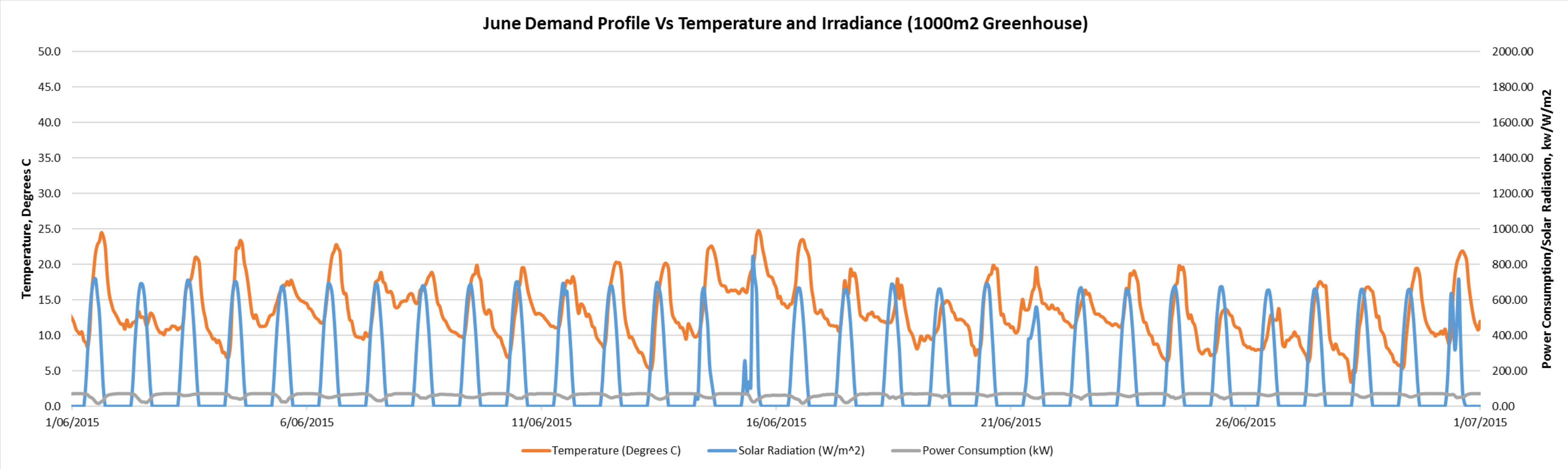

March Demand Profile Vs Temperature and Irradiance (1000m2 Greenhouse)
Temperature, Degrees C
Power Consumption/Solar Radiation, kw/W/m2
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
2000.00
1800.00
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
1/03/2015
6/03/2015
11/03/2015
16/03/2015
21/03/2015
26/03/2015
31/03/2015
Temperature (Degrees C)
Solar Radiation (W/m^2)
Power Consumption (kW)

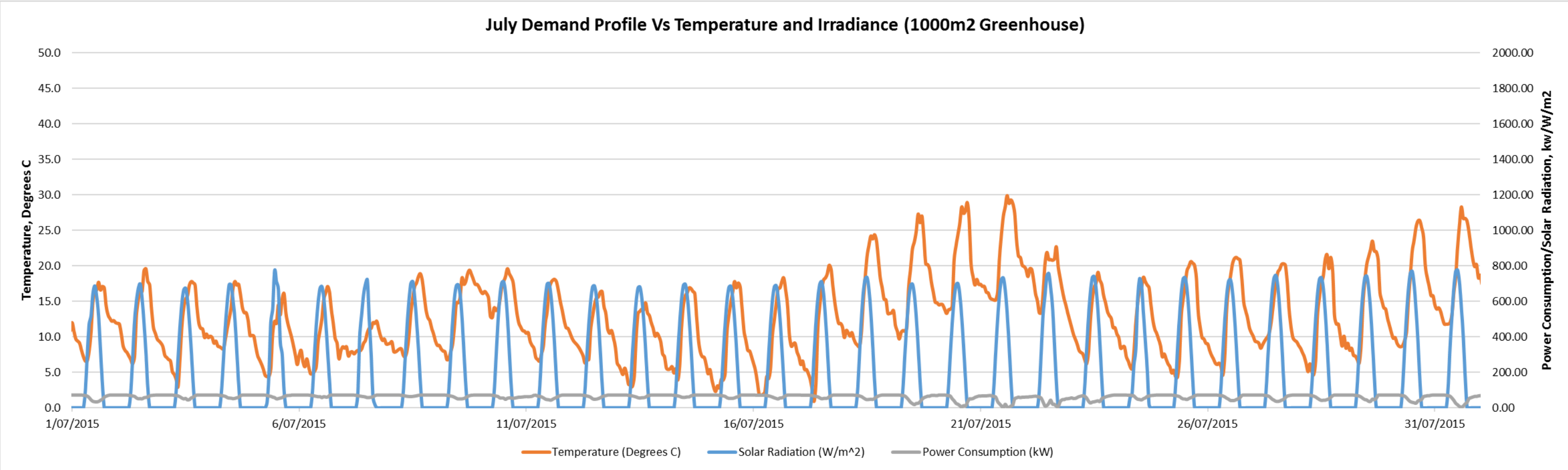


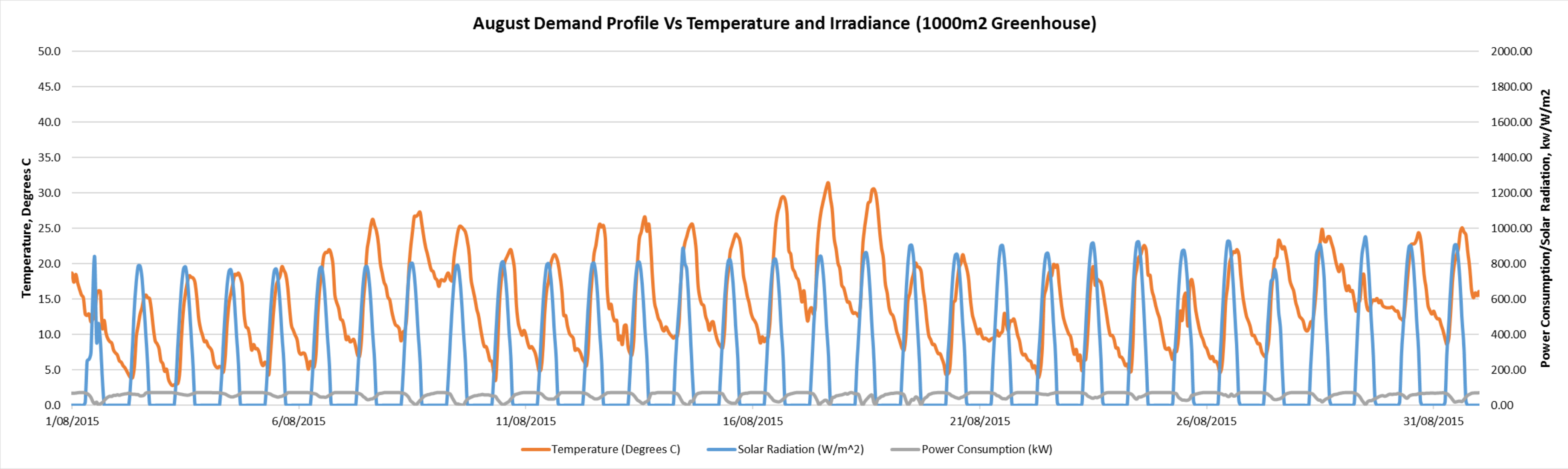
April Demand Profile Vs Temperature and Irradiance (1000m2 Greenhouse)
Temperature, Degrees C
Power Consumption/Solar Radiation, kw/W/m2
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
2000.00
1800.00
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
1/04/2015
6/04/2015
11/04/2015
16/04/2015
21/04/2015
26/04/2015
1/05/2015
Temperature (Degrees C)
Solar Radiation (W/m^2)
Power Consumption (kW)

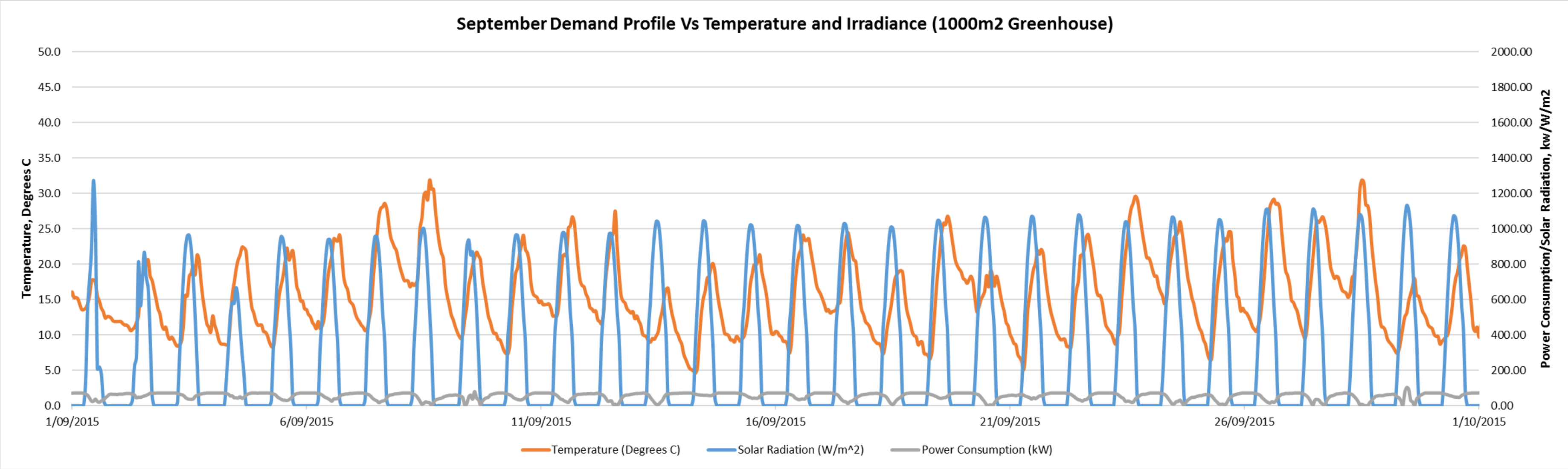


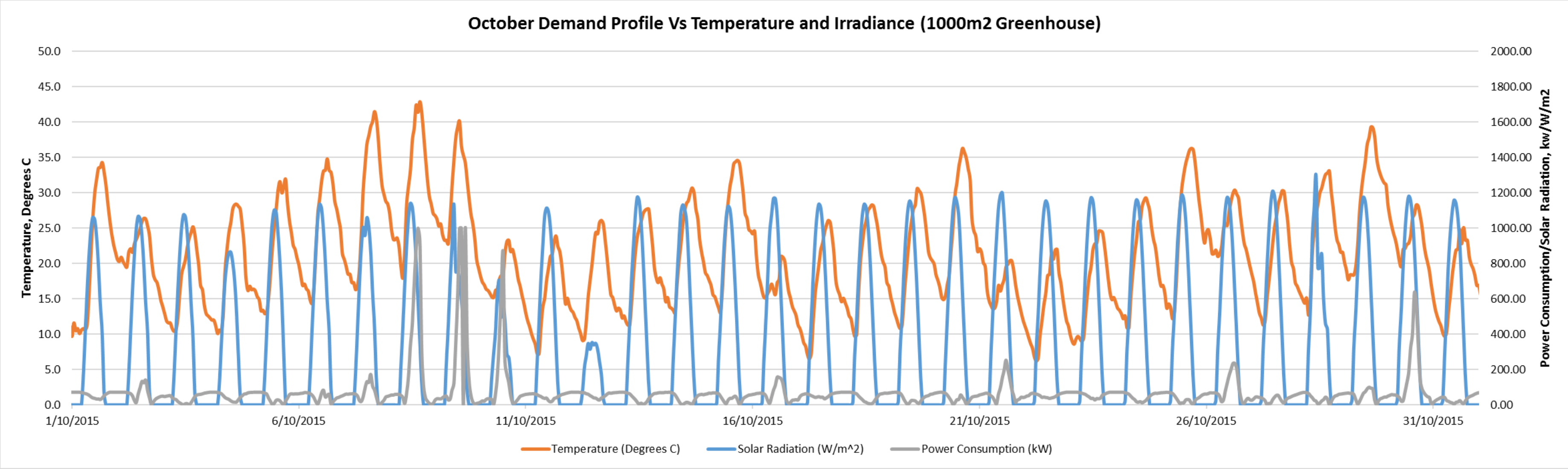
May Demand Profile Vs Temperature and Irradiance (1000m2 Greenhouse)
Temperature, Degrees C
Power Consumption/Solar Radiation, kw/W/m2
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
2000.00
1800.00
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
1/05/2015
6/05/2015
11/05/2015
16/05/2015
21/05/2015
26/05/2015
31/05/2015
Temperature (Degrees C)
Solar Radiation (W/m^2)
Power Consumption (kW)

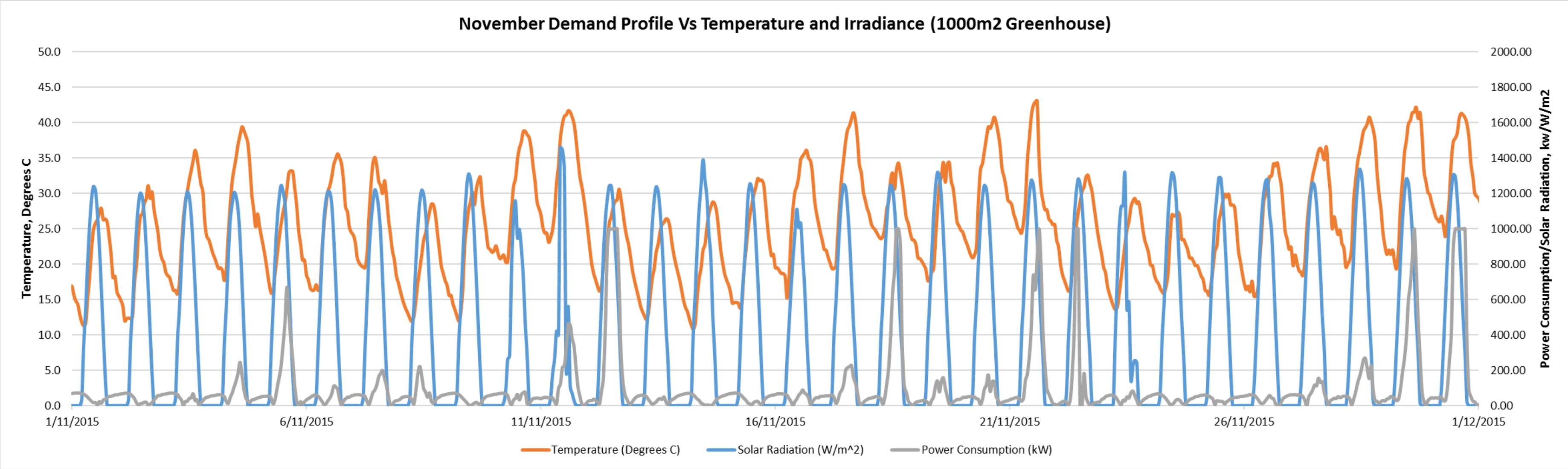

June Demand Profile Vs Temperature and Irradiance (1000m2 Greenhouse)
Temperature, Degrees C
Power Consumption/Solar Radiation, kw/W/m2
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
2000.00
1800.00
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
1/06/2015
6/06/2015
11/06/2015
16/06/2015
21/06/2015
26/06/2015
1/07/2015
Temperature (Degrees C)
Solar Radiation (W/m^2)
Power Consumption (kW)

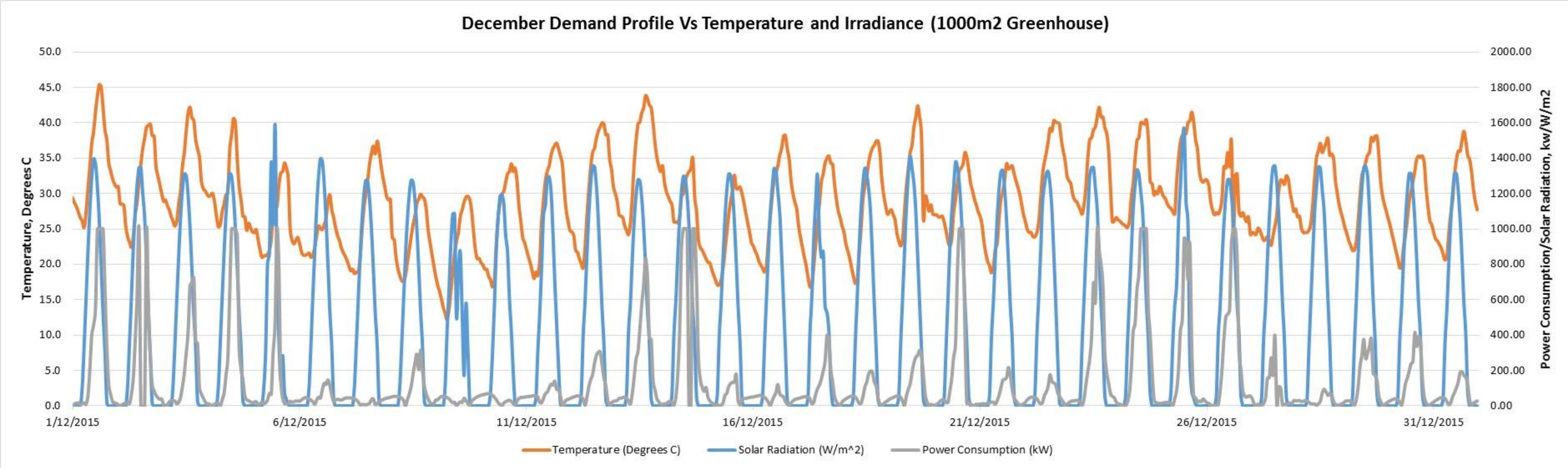

July Demand Profile Vs Temperature and Irradiance (1000m2 Greenhouse)
Temperature, Degrees C
Power Consumption/Solar Radiation, kw/W/m2
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
2000.00
1800.00
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
1/07/2015
6/07/2015
11/07/2015
16/07/2015
21/07/2015
26/07/2015
31/07/2015
Temperature (Degrees C)
Solar Radiation (W/m^2)
Power Consumption (kW)


August Demand Profile Vs Temperature and Irradiance (1000m2 Greenhouse)
Temperature, Degrees C
Power Consumption/Solar Radiation, kw/W/m2
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
2000.00
1800.00
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
1/08/2015
6/08/2015
11/08/2015
16/08/2015
21/08/2015
26/08/2015
31/08/2015
Temperature (Degrees C)
Solar Radiation (W/m^2)
Power Consumption (kW)


September Demand Profile Vs Temperature and Irradiance (1000m2 Greenhouse)
Temperature, Degrees C
Power Consumption/Solar Radiation, kw/W/m2
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
2000.00
1800.00
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
1/09/2015
6/09/2015
11/09/2015
16/09/2015
21/09/2015
26/09/2015
1/10/2015
Temperature (Degrees C)
Solar Radiation (W/m^2)
Power Consumption (kW)


October Demand Profile Vs Temperature and Irradiance (1000m2 Greenhouse)
Temperature, Degrees C
Power Consumption/Solar Radiation, kw/W/m2
1/10/2015
6/10/2015
11/10/2015
16/10/2015
21/10/2015
26/10/2015
31/10/2015
Temperature (Degrees C)
Solar Radiation (W/m^2)
Power Consumption (kW)

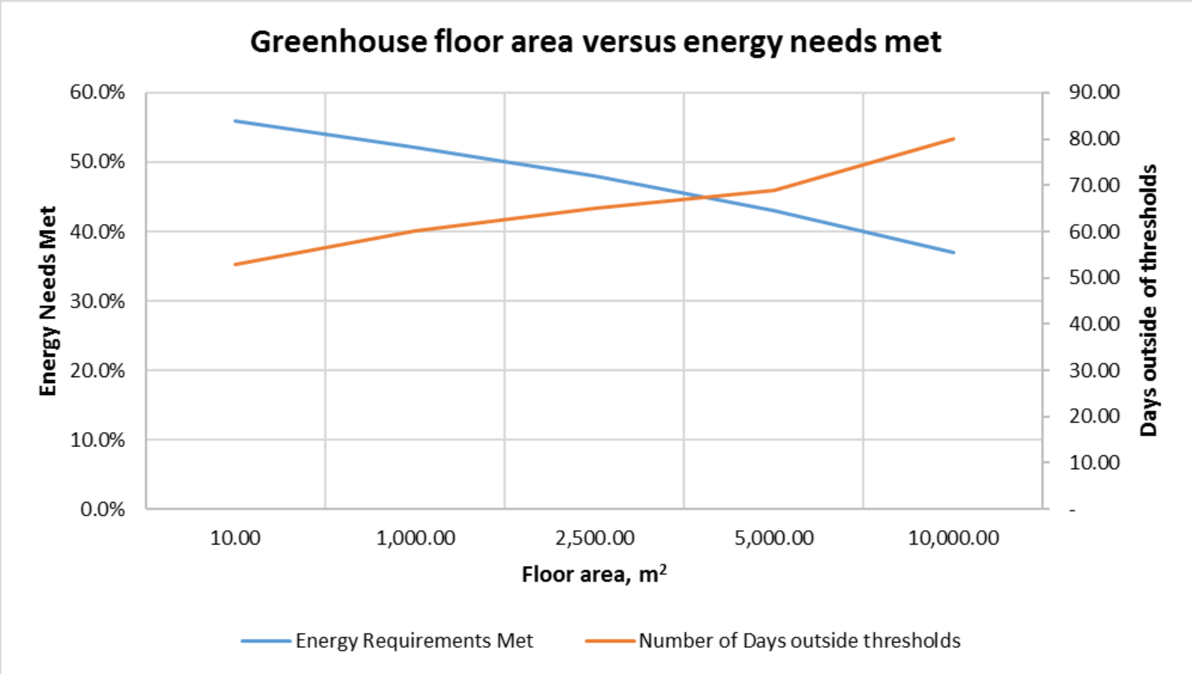

November Demand Profile Vs Temperature and Irradiance (1000m2 Greenhouse)
Temperature, Degrees C
Power Consumption/Solar Radiation, kw/W/m2
1/11/2015
6/11/2015
11/11/2015
16/11/2015
21/11/2015
26/11/2015
1/12/2015
Temperature (Degrees C)
Solar Radiation (W/m^2)
Power Consumption (kW)


December Demand Profile Vs Temperature and Irradiance (1000m2 Greenhouse)
Temperature, Degrees C
Power Consumption/Solar Radiation, kw/W/m2
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
2000.00
1800.00
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
1/12/2015
6/12/2015
11/12/2015
16/12/2015
21/12/2015
26/12/2015
31/12/2015
Temperature (Degrees C)
Solar Radiation (W/m^2)
Power Consumption (kW)

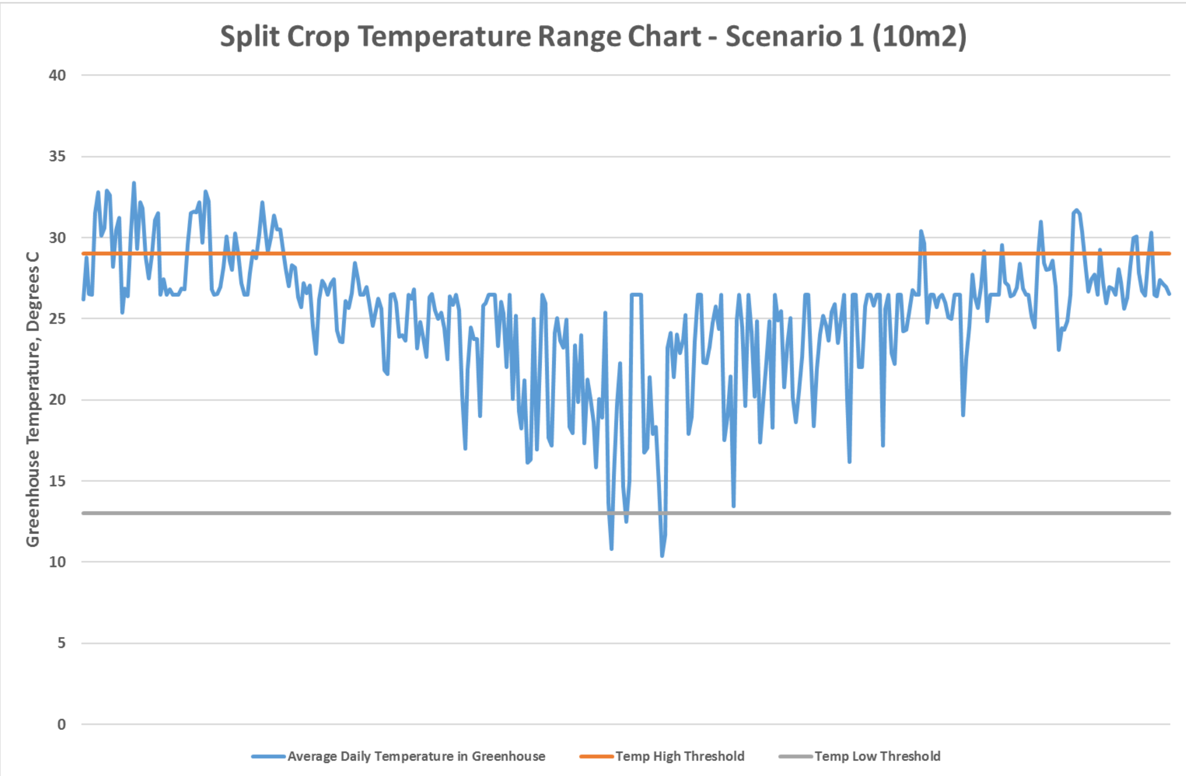
Appendix F – Scenario 1 Results

	1				
	Spill Only, No Diesel, No Battery, Single Crop (tomatoes), [Base Case]				
Critical Temperatures					
Split Crop?	No	No	No	No	No
Maximum 1	29	29	29	29	29
Minimum 1	13	13	13	13	13
Controlled Temperature 1	26.5	26.5	26.5	26.5	26.5
Greenhouse Size					
Base Floor Area	10000	10000	10000	10000	10000
Surface Area of Glass	11808	11808	11808	11808	11808
Glass Thickness	0.02	0.02	0.02	0.02	0.02
Length	100	100	100	100	100
Width	100	100	100	100	100
Ceiling Height	4	4	4	4	4
Roof Height	2	2	2	2	2
Battery Size					
Storage Capability	0	0	0	0	0
Discharge/Charge Capability	0	0	0	0	0
Portion not able to discharge	5%	5%	5%	5%	5%
Diesel Component					
Diesel Required?	No	No	No	No	No
No Summer Production off?	No	No	No	No	No
Growing Starts					
Growing Ends					
OUTPUT					
Possible Floor Area	10.00	1,000.00	2,500.00	5,000.00	10,000.00
No. days above critical temp	49.00	56.00	61.00	65.00	75.00
No. days below critical temp	4.00	4.00	4.00	4.00	5.00
Renewable shortfall	3.36	364.86	989.72	2,173.36	4,807.54
Energy Required	7.62	761.88	1,904.71	3,809.42	7,618.85
Total Shortfall	3.36	364.86	989.72	2,173.36	4,807.54
Renewable Energy Used	4.26	397.02	915.00	1,636.07	2,811.31
Energy Needs Met	55.9%	52.1%	48.0%	42.9%	36.9%

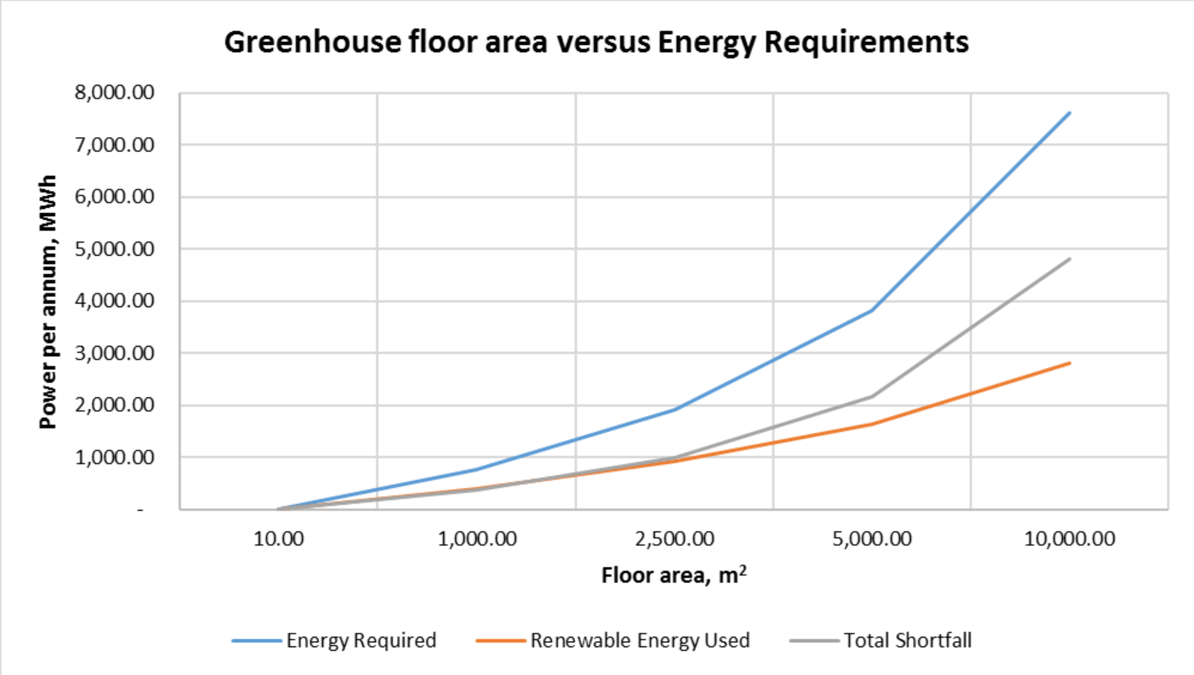
Greenhouse Energy relationship



Temperature Range Chart for Chosen Scenario



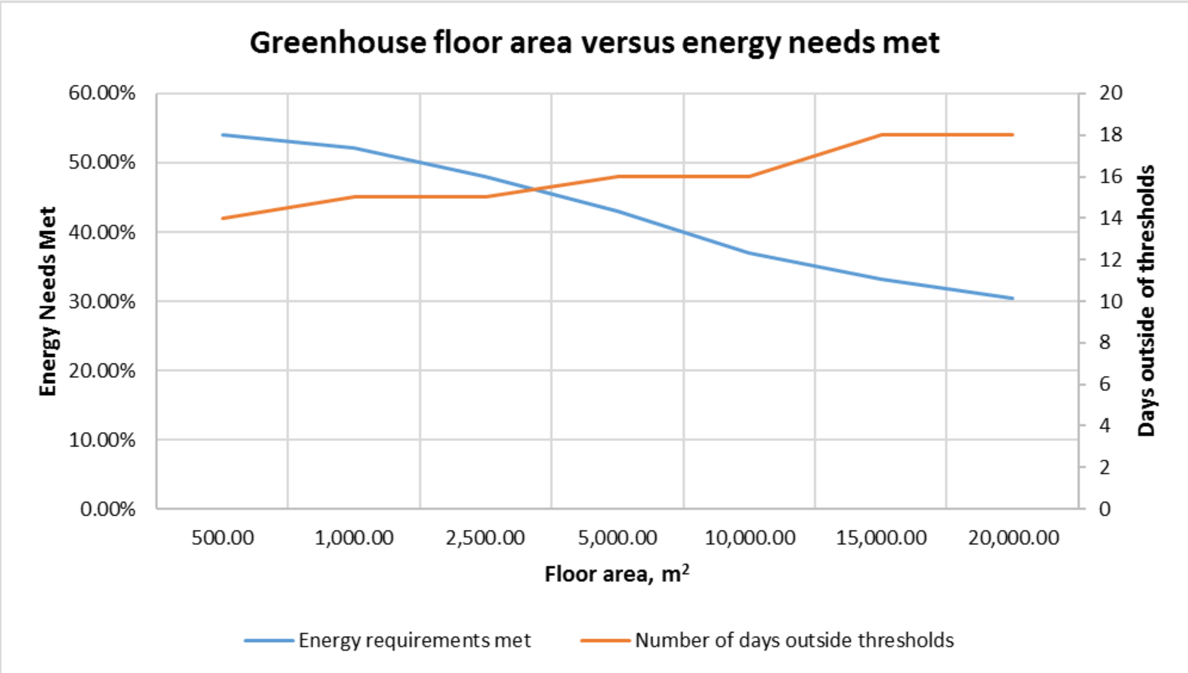
Relationship between energy requirements and floor area



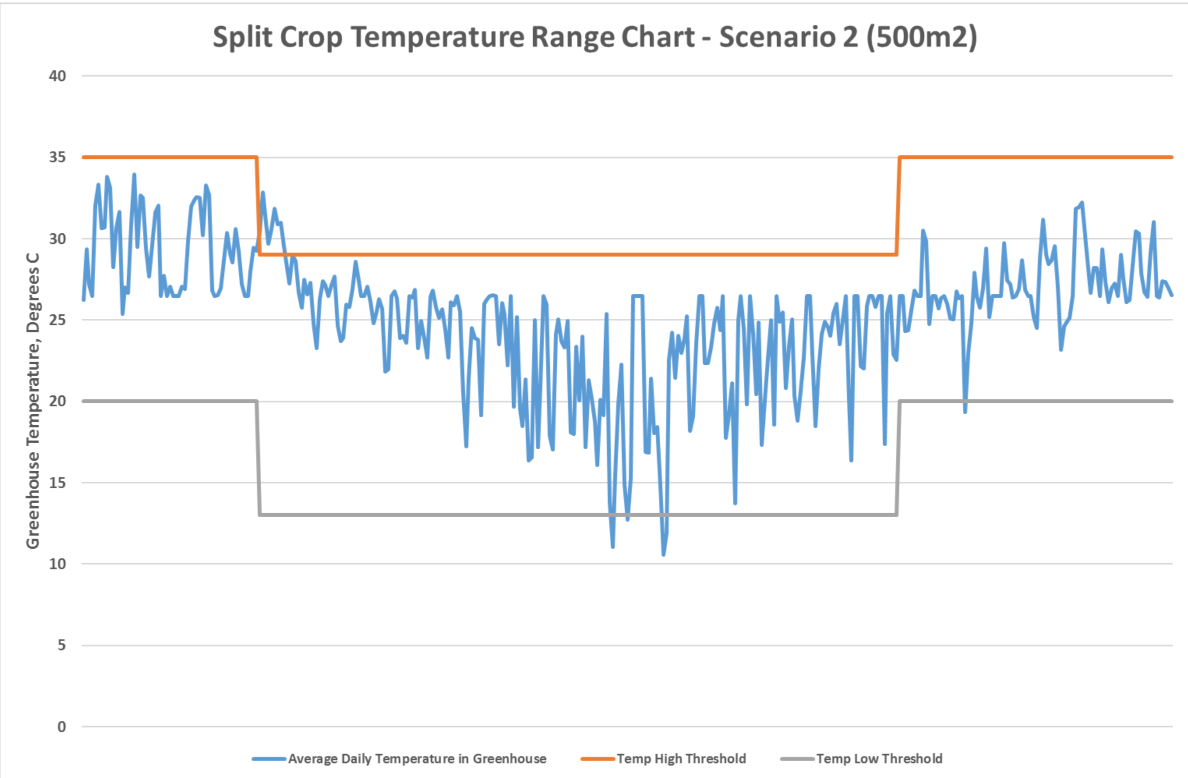
Appendix G – Scenario 2 Results

	2						
	Spill Only, No Diesel, No Battery, Split Crop (cucumber and Tomatoes)						
Critical Temperatures							
Split Crop?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Maximum 1	35	35	35	35	35	35	35
Minimum 1	20	20	20	20	20	20	20
Control Temp 1	26.5	26.5	26.5	26.5	26.5	26.5	26.5
Growing 1 Start	1/01/15	1/01/15	1/01/15	1/01/15	1/01/15	1/01/15	1/01/15
Growing 1 End	1/03/15	1/03/15	1/03/15	1/03/15	1/03/15	1/03/15	1/03/15
Growing 2 Start	1/10/15	1/10/15	1/10/15	1/10/15	1/10/15	1/10/15	1/10/15
Growing 2 End	1/01/16	1/01/16	1/01/16	1/01/16	1/01/16	1/01/16	1/01/16
Maximum 2	29	29	29	29	29	29	29
Minimum 2	13	13	13	13	13	13	13
Control Temp 2	26.5	26.5	26.5	26.5	26.5	26.5	26.5
Growing 3 Start	1/03/15	1/03/15	1/03/15	1/03/15	1/03/15	1/03/15	1/03/15
Growing 3 End	1/10/15	1/10/15	1/10/15	1/10/15	1/10/15	1/10/15	1/10/15
Greenhouse Size							
Base Floor Area	10000	10000	10000	10000	10000	10000	10000
Surface Area of Glass	11808	11808	11808	11808	11808	11808	11808
Glass Thickness	0.015	0.015	0.015	0.015	0.015	0.015	0.015
Length	100	100	100	100	100	100	100
Width	100	100	100	100	100	100	100
Ceiling Height	4	4	4	4	4	4	4
Roof Height	2	2	2	2	2	2	2
OUTPUT							
Possible Floor Area	10,000	5,000	2,500	1,000	500	15,000	20,000
No. days above critical	11	11	10	10	9	12	12
No. days below critical	5	5	5	5	5	6	6
Renewable shortfall	4,808	2,173	990	365	175	7,630	10,598
Energy Required	7,619	3,809	1,905	762	381	11,428	15,238
Diesel Used	0	0	0	0	0	0	0
Total Shortfall	4,808	2,173	990	365	175	7,630	10,598
Renewable Energy	2,811	1,636	915	397	206	3,799	4,640
Battery usage	1	1	2	2	2	1	1
Battery Discharge to	1	1	2	2	2	1	1
Energy Spilled	0	0	0	0	0	0	0
Energy Needs Met	36.9%	42.9%	48.0%	52.1%	54.0%	33.2%	30.4%

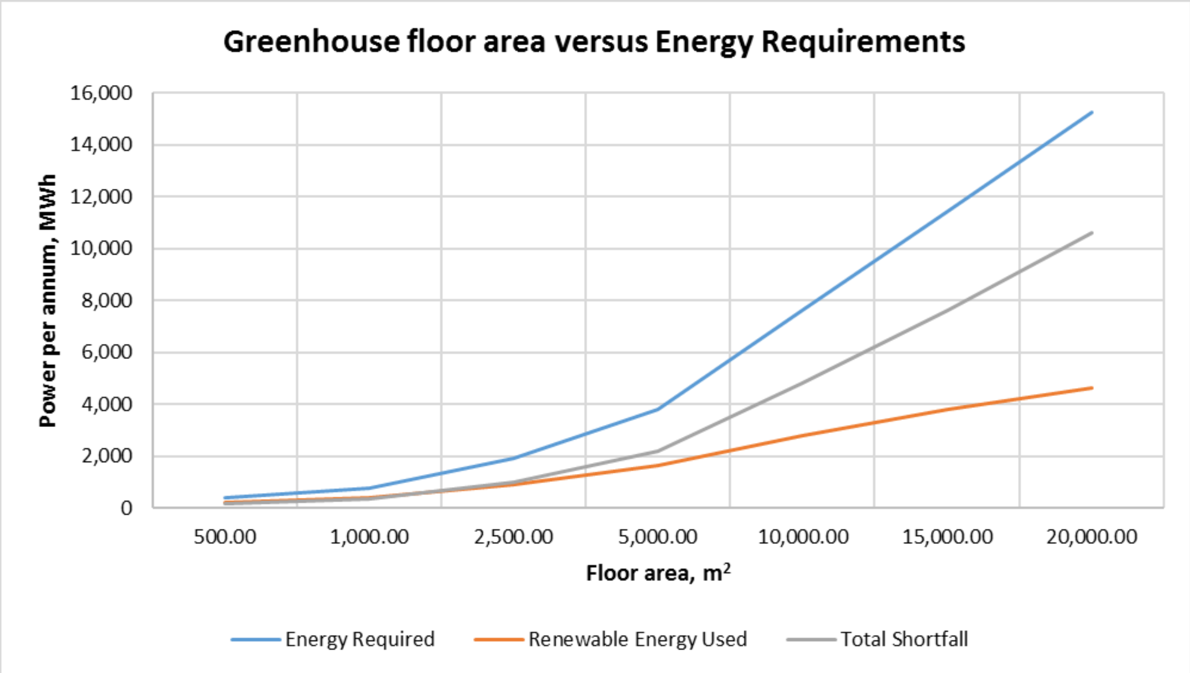
Greenhouse Energy relationship



Temperature Range Chart for Chosen Scenario



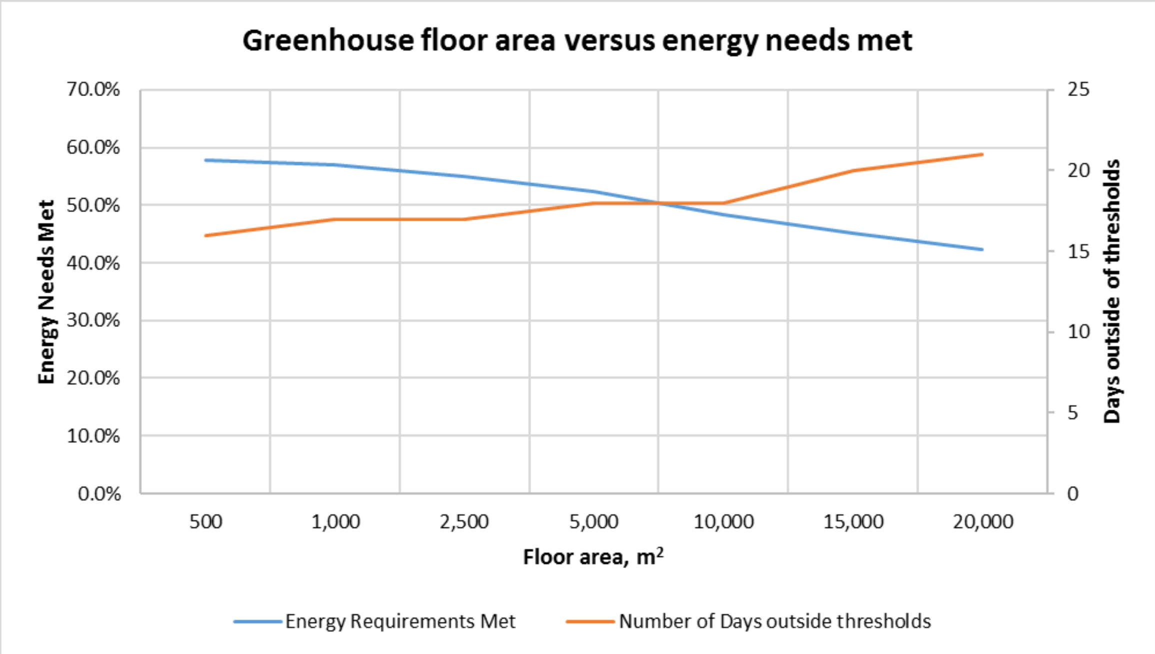
Relationship between energy requirements and floor area



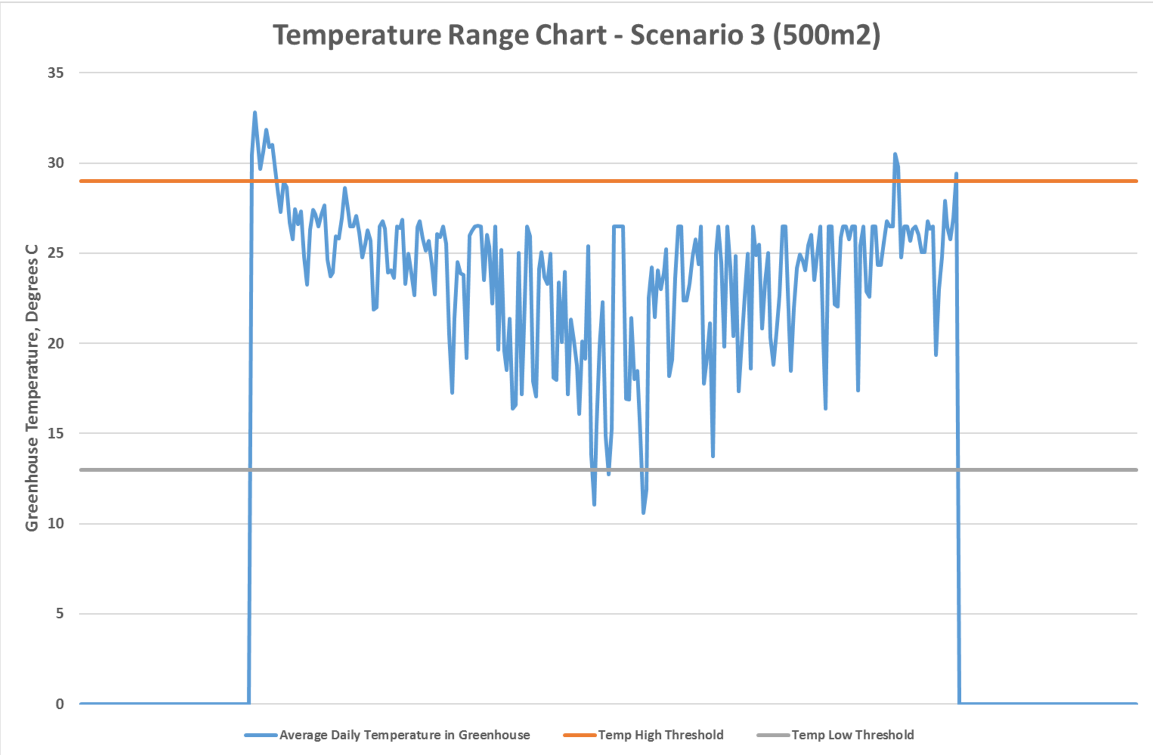
Appendix H – Scenario 3 Results

	3						
	Spill only, no summer, no Diesel, No Battery, Single Crop (Tomatoes)						
Critical Temperatures							
Split Crop?	No	No	No	No	No	No	No
Maximum 1	29	29	29	29	29	29	29
Minimum 1	13	13	13	13	13	13	13
Control Temp	26.5	26.5	26.5	26.5	26.5	26.5	26.5
Greenhouse Size							
Base Floor Area	10000	10000	10000	10000	10000	10000	10000
Surface Area	11808	11808	11808	11808	11808	11808	11808
Glass Thickness	0.015	0.015	0.015	0.015	0.015	0.015	0.015
Length	100	100	100	100	100	100	100
Width	100	100	100	100	100	100	100
Ceiling Height	4	4	4	4	4	4	4
Roof Height	2	2	2	2	2	2	2
Summer Production							
No Summer Production?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Growing Starts	1/03/15	1/03/15	1/03/15	1/03/15	1/03/15	1/03/15	1/03/15
Growing Ends	31/10/15	31/10/15	31/10/15	31/10/15	31/10/15	31/10/15	31/10/15
OUTPUT							
Possible Floor Area	500	1,000	2,500	5,000	10,000	15,000	20,000
No. days above critical	12	13	13	14	14	15	16
No. days below critical	4	4	4	4	4	5	5
Renewable shortfall	77	158	414	874	1,896	3,015	4,228
Energy Required	183	367	917	1,834	3,668	5,503	7,337
Total Shortfall	77	158	414	874	1,896	3,015	4,228
Renewable Energy Used	106	209	504	960	1,772	2,488	3,109
Energy Needs Met	57.9%	57.0%	54.9%	52.3%	48.3%	45.2%	42.4%

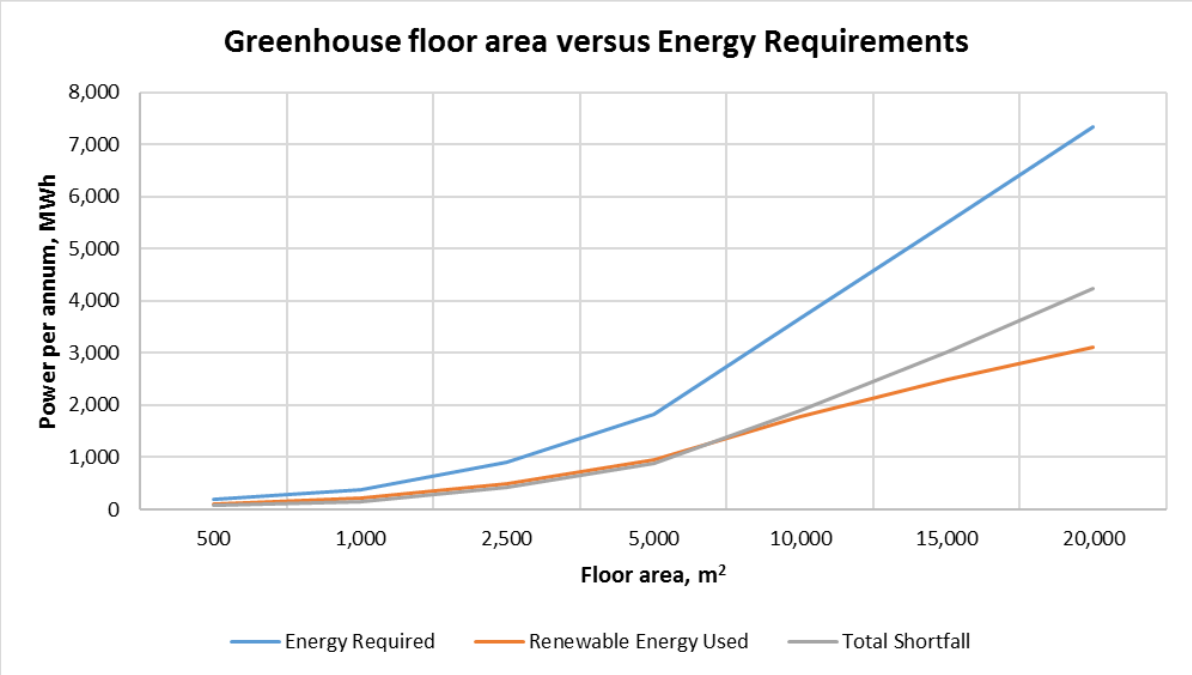
Greenhouse Energy relationship



Temperature Range Chart for Chosen Scenario



Relationship between energy requirements and floor area



Appendix I – Scenario 4 Results

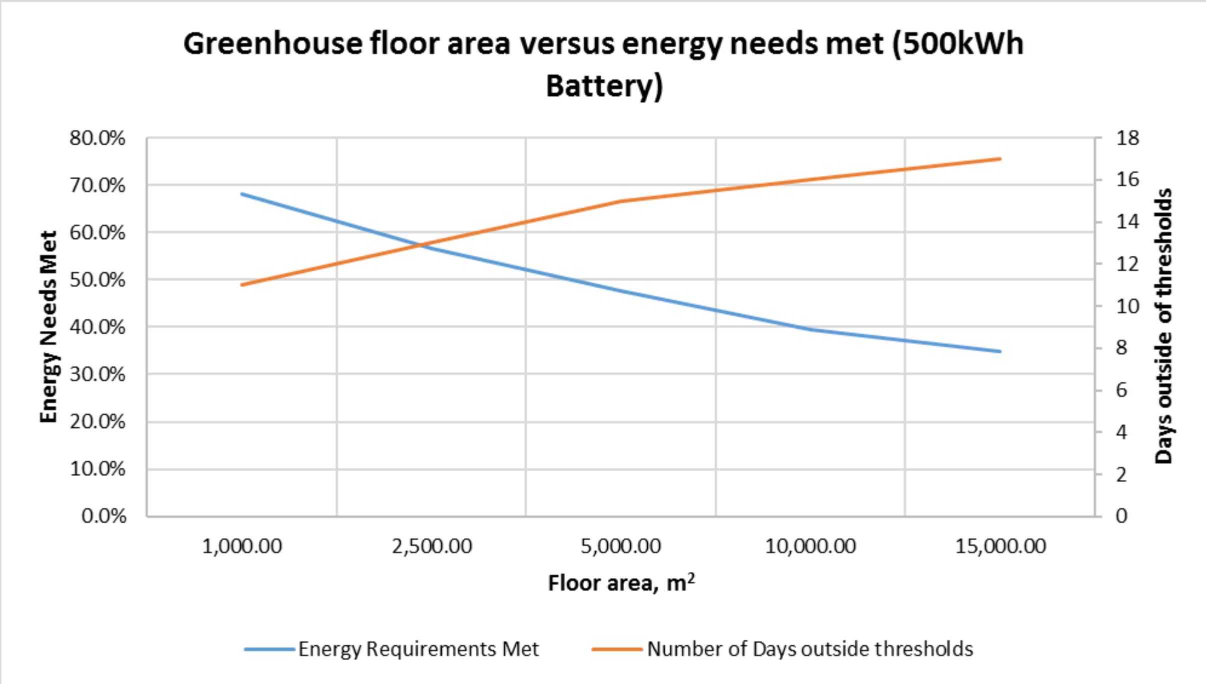
	4				
	Spill, Battery Included, No Diesel, Split Crop (Cucumber and Tomatoes), 500kWh Battery				
Critical Temperatures					
Split Crop?	Yes	Yes	Yes	Yes	Yes
Maximum 1	35	35	35	35	35
Minimum 1	20	20	20	20	20
Controlled Temp	26.5	26.5	26.5	26.5	26.5
Growing 1 Start	1/01/15	1/01/15	1/01/15	1/01/15	1/01/15
Growing 1 End	1/03/15	1/03/15	1/03/15	1/03/15	1/03/15
Growing 2 Start	1/10/15	1/10/15	1/10/15	1/10/15	1/10/15
Growing 2 End	1/01/16	1/01/16	1/01/16	1/01/16	1/01/16
Maximum 2	29	29	29	29	29
Minimum 2	13	13	13	13	13
Controlled Temp 2	26.5	26.5	26.5	26.5	26.5
Growing 3 Start	1/03/15	1/03/15	1/03/15	1/03/15	1/03/15
Growing 3 End	1/10/15	1/10/15	1/10/15	1/10/15	1/10/15
Greenhouse Size					
Base Floor Area	10000	10000	10000	10000	10000
Surface Area of Glass	11808	11808	11808	11808	11808
Glass Thickness	0.015	0.015	0.015	0.015	0.015
Length	100	100	100	100	100
Width	100	100	100	100	100
Ceiling Height	4	4	4	4	4
Roof Height	2	2	2	2	2
Battery Size					
Storage Capability	500	500	500	500	500
Discharge/Charge Capability	500	500	500	500	500
Portion not able to discharge	5%	5%	5%	5%	5%
OUTPUT					
Possible Floor Area	1,000	2,500	5,000	10,000	15,000
No. days above critical	8	10	11	11	12
No. days below critical	3	3	4	5	5
Renewable shortfall	243.76	827.09	1,995.80	4,620.19	7,436.47
Energy Required	761.88	1,904.71	3,809.42	7,618.85	11,428.27
Diesel Used	0.00	0.00	0.00	0.00	0.00
Total Shortfall	243.76	827.09	1,995.80	4,620.19	7,436.47
Renewable Energy Used	518.13	1,077.62	1,813.62	2,998.66	3,991.80
Battery usage	121.11	162.62	177.56	187.35	193.12
Energy Needs Met	68.0%	56.6%	47.6%	39.4%	34.9%

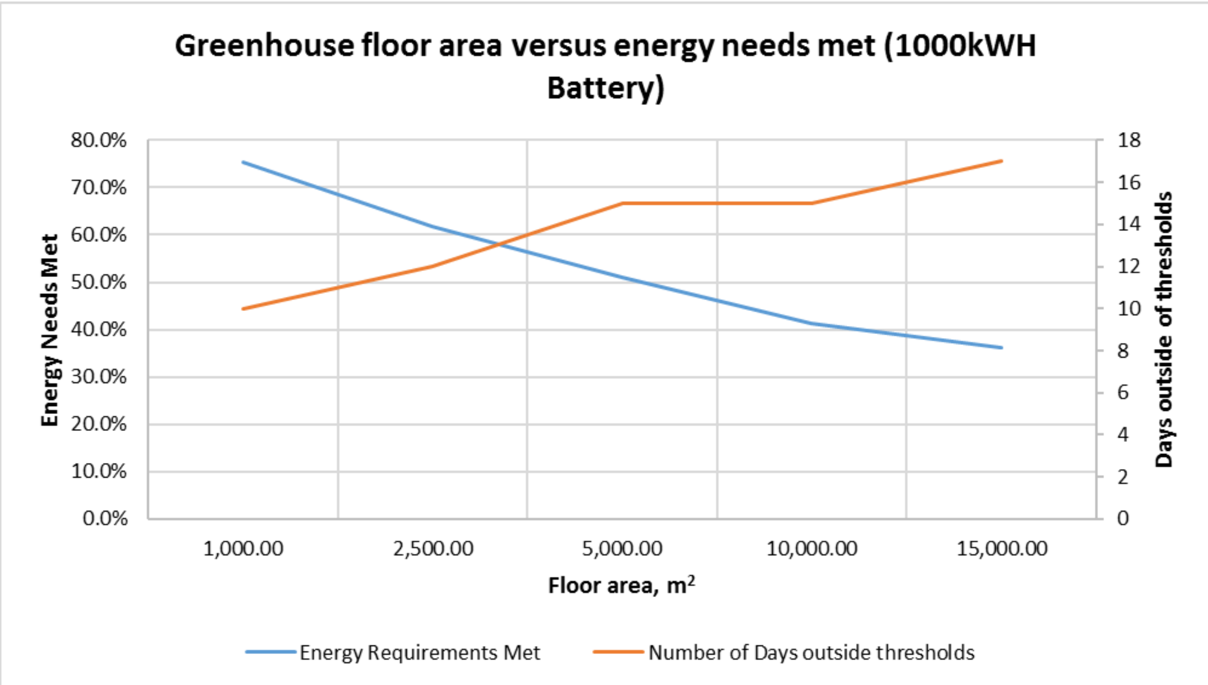
	4				
	Spill, Battery Included, No Diesel, Split Crop (Cucumber and Tomatoes), 1000kWh Battery				
Critical Temperatures					
Split Crop?	Yes	Yes	Yes	Yes	Yes
Maximum 1	35	35	35	35	35
Minimum 1	20	20	20	20	20
Controlled Temp 1	26.5	26.5	26.5	26.5	26.5
Growing 1 Start	1/01/2015	1/01/2015	1/01/2015	1/01/2015	1/01/2015
Growing 1 End	1/03/2015	1/03/2015	1/03/2015	1/03/2015	1/03/2015
Growing 2 Start	1/10/2015	1/10/2015	1/10/2015	1/10/2015	1/10/2015
Growing 2 End	1/01/2016	1/01/2016	1/01/2016	1/01/2016	1/01/2016
Maximum 2	29	29	29	29	29
Minimum 2	13	13	13	13	13
Controlled Temp 2	26.5	26.5	26.5	26.5	26.5
Growing 3 Start	1/03/2015	1/03/2015	1/03/2015	1/03/2015	1/03/2015
Growing 3 End	1/10/2015	1/10/2015	1/10/2015	1/10/2015	1/10/2015
Greenhouse Size					
Base Floor Area	10000	10000	10000	10000	10000
Surface Area of Glass	11808	11808	11808	11808	11808
Glass Thickness	0.015	0.015	0.015	0.015	0.015
Length	100	100	100	100	100
Width	100	100	100	100	100
Ceiling Height	4	4	4	4	4
Roof Height	2	2	2	2	2
Battery Size					
Storage Capability	1000	1000	1000	1000	1000
Discharge/Charge Capability	1000	1000	1000	1000	1000
Portion not able to discharge	5%	5%	5%	5%	5%
OUTPUT					
Possible Floor Area	1,000.00	2,500.00	5,000.00	10,000.00	15,000.00
No. days above critical	7.00	9.00	11.00	11.00	12.00
No. days below critical	3.00	3.00	4.00	4.00	5.00
Renewable shortfall	186.98	726.51	1,864.87	4,478.67	7,290.82
Energy Required	761.88	1,904.71	3,809.42	7,618.85	11,428.27
Diesel Used	0.00	0.00	0.00	0.00	0.00
Total Shortfall	186.98	726.51	1,864.87	4,478.67	7,290.82
Renewable Energy Used	574.91	1,178.20	1,944.56	3,140.18	4,137.45
Battery usage	177.89	263.20	308.49	328.87	338.77
Energy Needs Met	75.5%	61.9%	51.0%	41.2%	36.2%

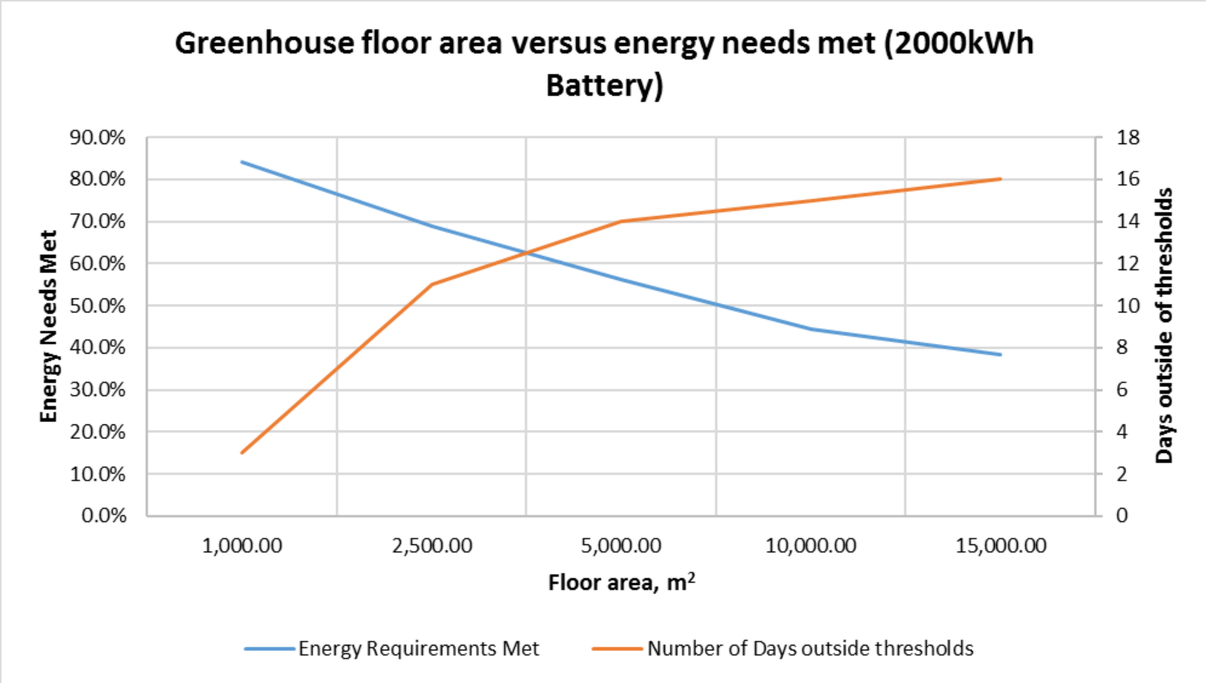
	4				
	Spill, Battery Included, No Diesel, Split Crop (Cucumber and Tomatoes), 2000kWh Battery				
Critical Temperatures					
Split Crop?	Yes	Yes	Yes	Yes	Yes
Maximum 1	35	35	35	35	35
Minimum 1	20	20	20	20	20
Controlled Temp 1	26.5	26.5	26.5	26.5	26.5
Growing 1 Start	1/01/2015	1/01/2015	1/01/2015	1/01/2015	1/01/2015
Growing 1 End	1/03/2015	1/03/2015	1/03/2015	1/03/2015	1/03/2015
Growing 2 Start	1/10/2015	1/10/2015	1/10/2015	1/10/2015	1/10/2015
Growing 2 End	1/01/2016	1/01/2016	1/01/2016	1/01/2016	1/01/2016
Maximum 2	29	29	29	29	29
Minimum 2	13	13	13	13	13
Controlled Temp 2	26.5	26.5	26.5	26.5	26.5
Growing 3 Start	1/03/2015	1/03/2015	1/03/2015	1/03/2015	1/03/2015
Growing 3 End	1/10/2015	1/10/2015	1/10/2015	1/10/2015	1/10/2015
Greenhouse Size					
Base Floor Area	10000	10000	10000	10000	10000
Surface Area of Glass	11808	11808	11808	11808	11808
Glass Thickness	0.015	0.015	0.015	0.015	0.015
Length	100	100	100	100	100
Width	100	100	100	100	100
Ceiling Height	4	4	4	4	4
Roof Height	2	2	2	2	2
Battery Size					
Storage Capability	2000	2000	2000	2000	2000
Discharge/Charge Capability	2000	2000	2000	2000	2000
Portion not able to discharge	5%	5%	5%	5%	5%
OUTPUT					
Possible Floor Area	1,000.00	2,500.00	5,000.00	10,000.00	15,000.00
No. days above critical temp	2.00	8.00	10.00	11.00	12.00
No. days below critical temp	1.00	3.00	4.00	4.00	4.00
Renewable shortfall	120.61	594.30	1,669.51	4,244.19	7,048.28
Energy Required	761.88	1,904.71	3,809.42	7,618.85	11,428.27
Diesel Used	0.00	0.00	0.00	0.00	0.00
Total Shortfall	120.61	594.30	1,669.51	4,244.19	7,048.28
Renewable Energy Used	641.27	1,310.41	2,139.91	3,374.66	4,379.99
Battery usage	244.25	395.41	503.85	563.35	581.31
Energy Needs Met	84.2%	68.8%	56.2%	44.3%	38.3%

	4				
	Spill, Battery Included, No Diesel, Split Crop (Cucumber and Tomatoes), 5000kWh Battery				
Critical Temperatures					
Split Crop?	Yes	Yes	Yes	Yes	Yes
Maximum 1	35	35	35	35	35
Minimum 1	20	20	20	20	20
Controlled Temp 1	26.5	26.5	26.5	26.5	26.5
Growing 1 Start	1/01/2015	1/01/2015	1/01/2015	1/01/2015	1/01/2015
Growing 1 End	1/03/2015	1/03/2015	1/03/2015	1/03/2015	1/03/2015
Growing 2 Start	1/10/2015	1/10/2015	1/10/2015	1/10/2015	1/10/2015
Growing 2 End	1/01/2016	1/01/2016	1/01/2016	1/01/2016	1/01/2016
Maximum 2	29	29	29	29	29
Minimum 2	13	13	13	13	13
Controlled Temp 2	26.5	26.5	26.5	26.5	26.5
Growing 3 Start	1/03/2015	1/03/2015	1/03/2015	1/03/2015	1/03/2015
Growing 3 End	1/10/2015	1/10/2015	1/10/2015	1/10/2015	1/10/2015
Greenhouse Size					
Base Floor Area	10000	10000	10000	10000	10000
Surface Area of Glass	11808	11808	11808	11808	11808
Glass Thickness	0.015	0.015	0.015	0.015	0.015
Length	100	100	100	100	100
Width	100	100	100	100	100
Ceiling Height	4	4	4	4	4
Roof Height	2	2	2	2	2
Battery Size					
Storage Capability	5000	5000	5000	5000	5000
Discharge/Charge Capability	5000	5000	5000	5000	5000
Portion not able to discharge	5%	5%	5%	5%	5%
OUTPUT					
Possible Floor Area	1,000.00	2,500.00	5,000.00	10,000.00	15,000.00
No. days above critical temp	1.00	5.00	9.00	11.00	11.00
No. days below critical temp	0.00	1.00	4.00	4.00	4.00
Renewable shortfall	28.48	369.98	1,307.53	3,751.74	6,506.99
Energy Required	761.88	1,904.71	3,809.42	7,618.85	11,428.27
Diesel Used	0.00	0.00	0.00	0.00	0.00
Total Shortfall	28.48	369.98	1,307.53	3,751.74	6,506.99
Renewable Energy Used	733.40	1,534.73	2,501.89	3,867.11	4,921.28
Battery usage	336.38	619.73	865.82	1,055.80	1,122.60
Energy Needs Met	96.3%	80.6%	65.7%	50.8%	43.1%

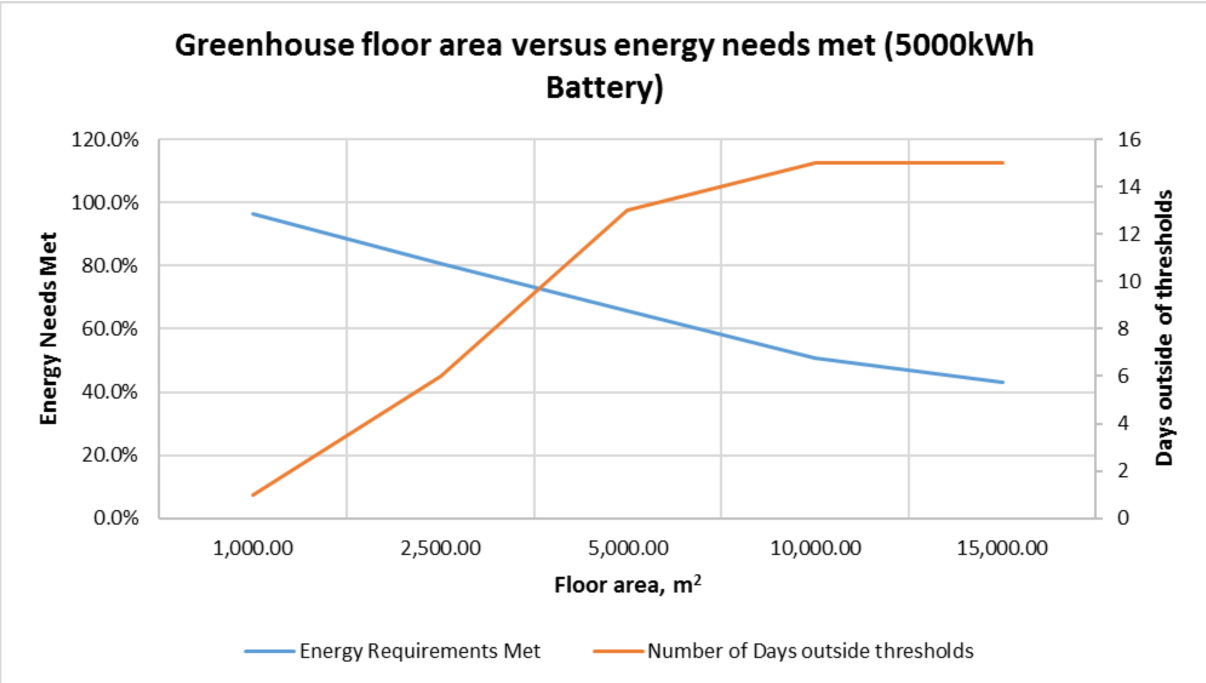
Greenhouse Energy Relationship





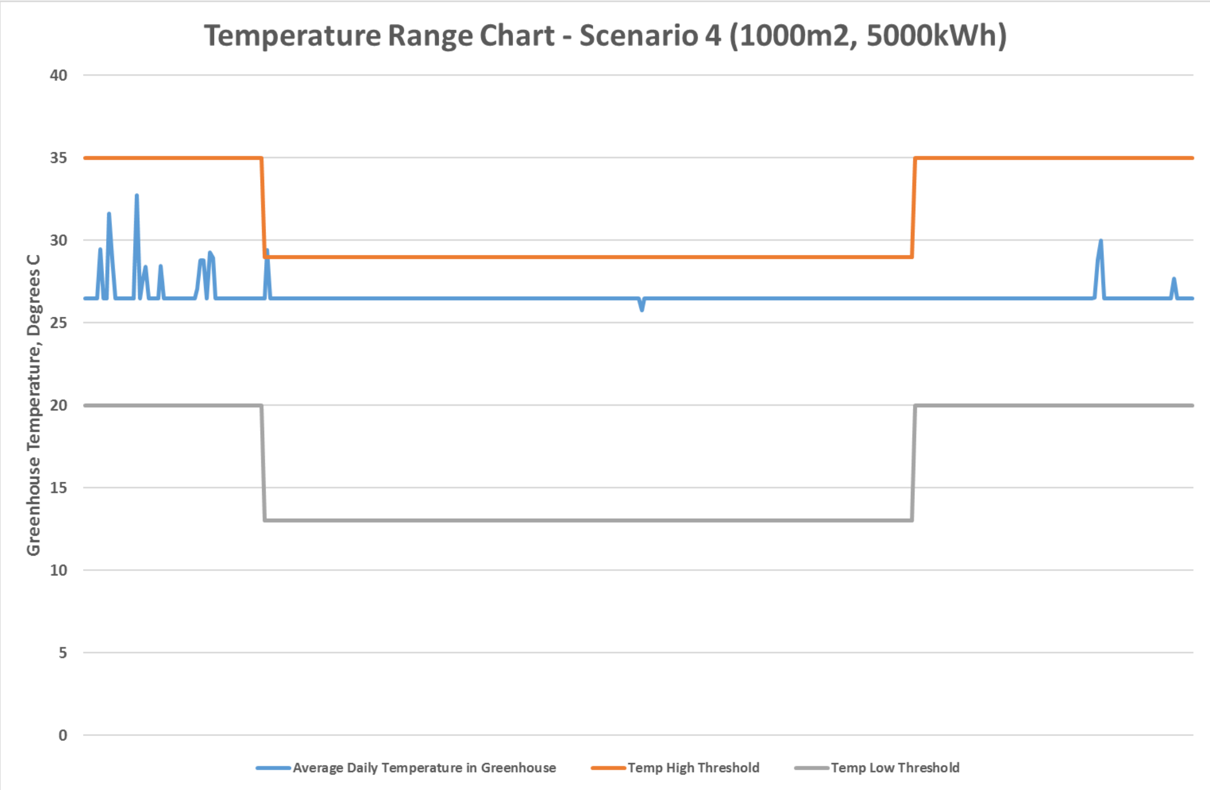


Greenhouse floor area versus energy needs met (2000kWh Battery)
Energy Needs Met
90.0%
80.0%
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
18
16
14
12
10
8
6
4
2
0
Days outside of thresholds
1,000.00
2,500.00
5,000.00
10,000.00
15,000.00
Floor area, m²
Energy Requirements Met
Number of Days outside thresholds

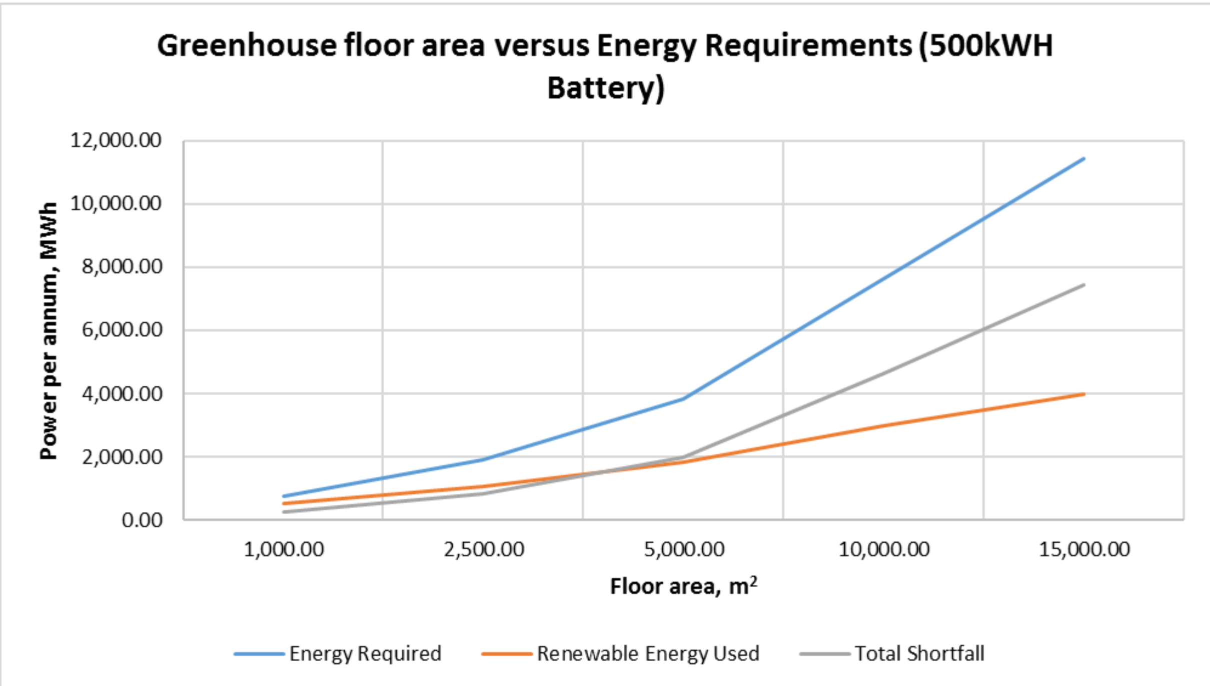


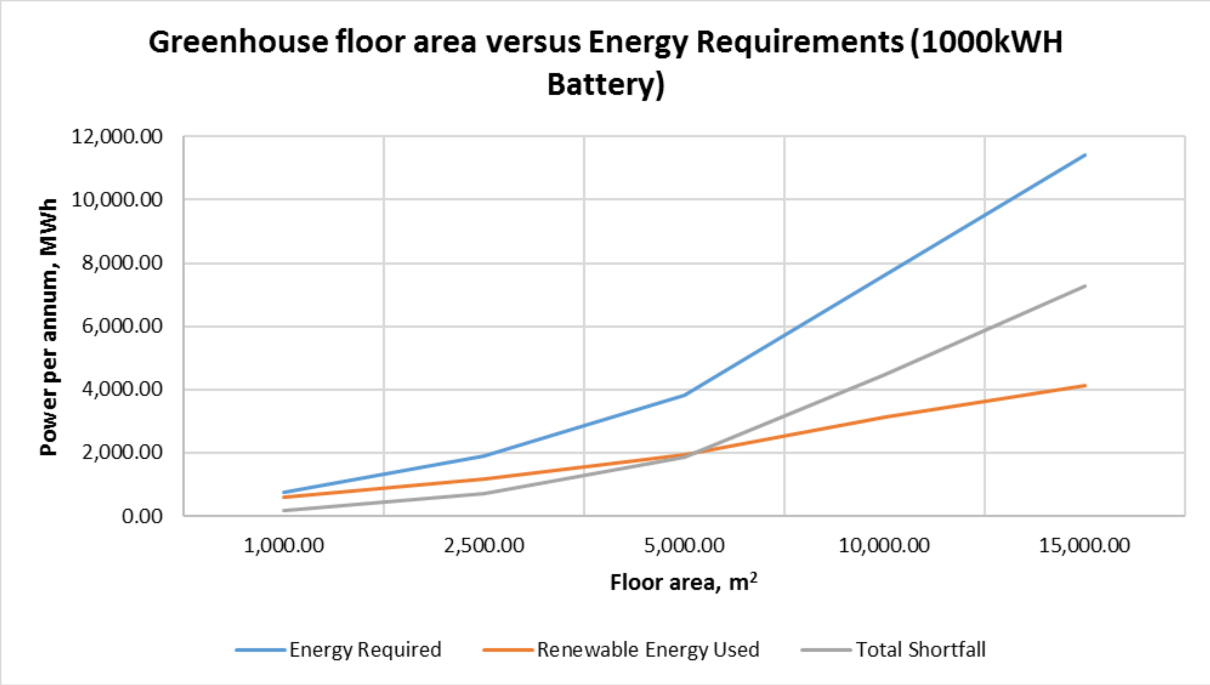
Greenhouse floor area versus energy needs met (5000kWh Battery)
Energy Needs Met
120.0%
100.0%
80.0%
60.0%
40.0%
20.0%
0.0%
16
14
12
10
8
6
4
2
0
Days outside of thresholds
1,000.00
2,500.00
5,000.00
10,000.00
15,000.00
Floor area, m²
Energy Requirements Met
Number of Days outside thresholds

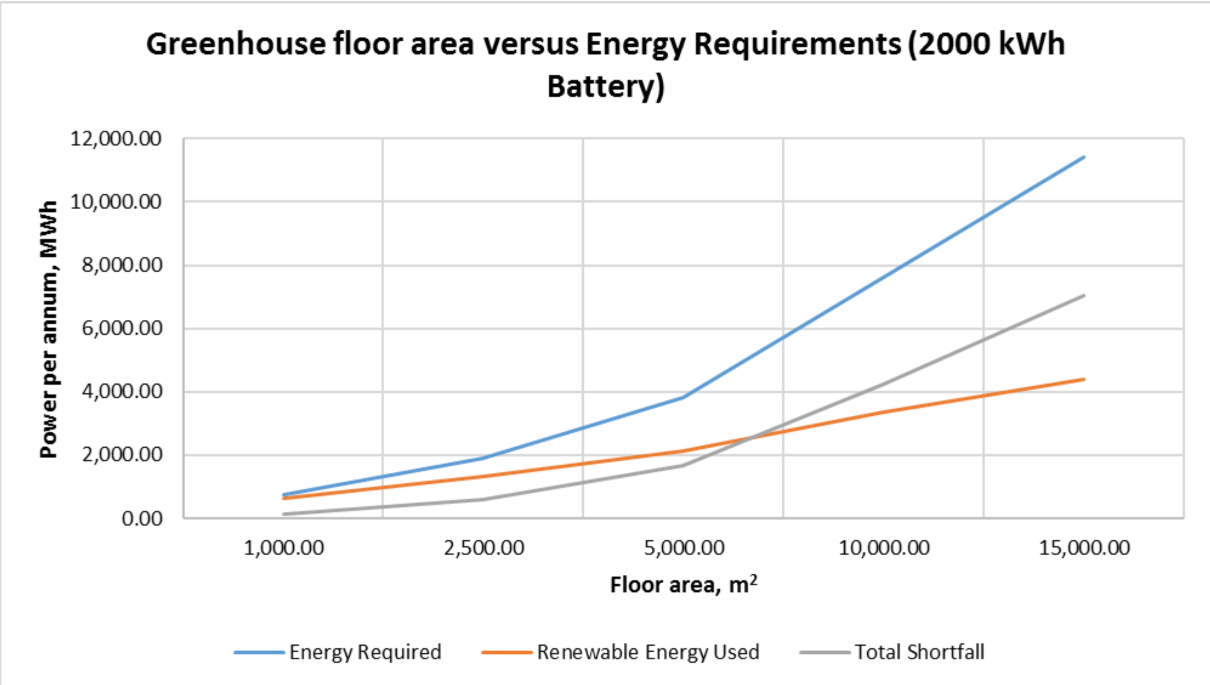
Temperature Range Chart for Chosen Scenario

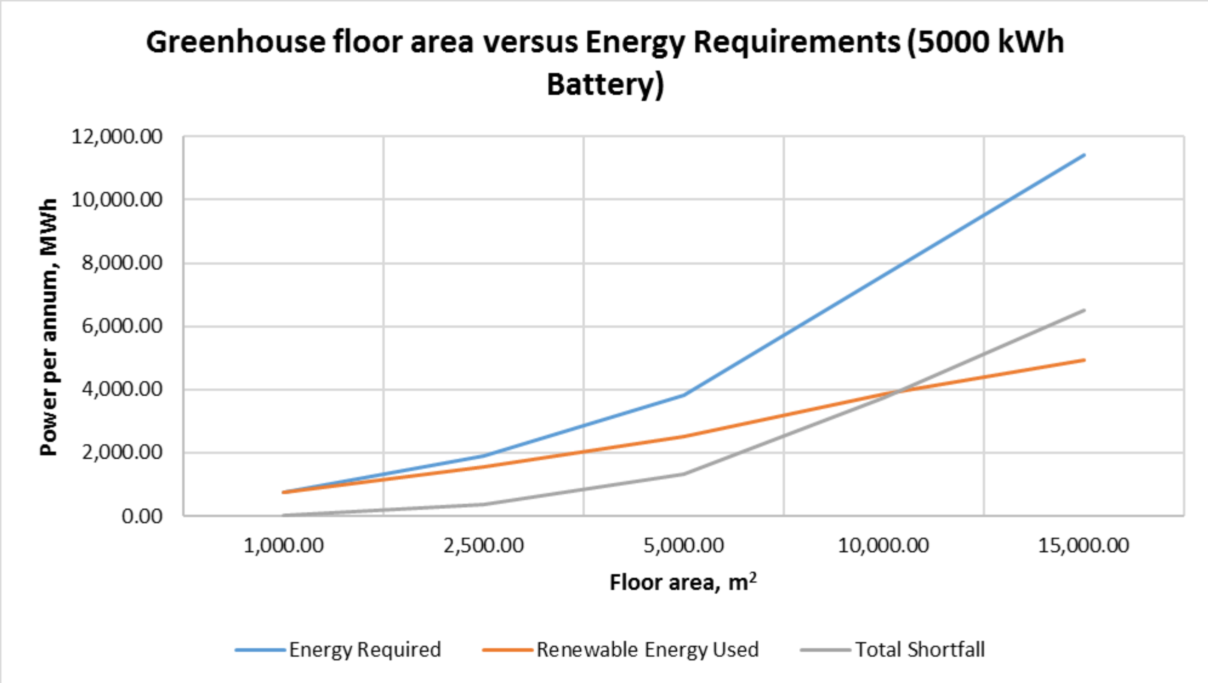


Relationship Between Energy Requirements, Floor Area and Battery Size

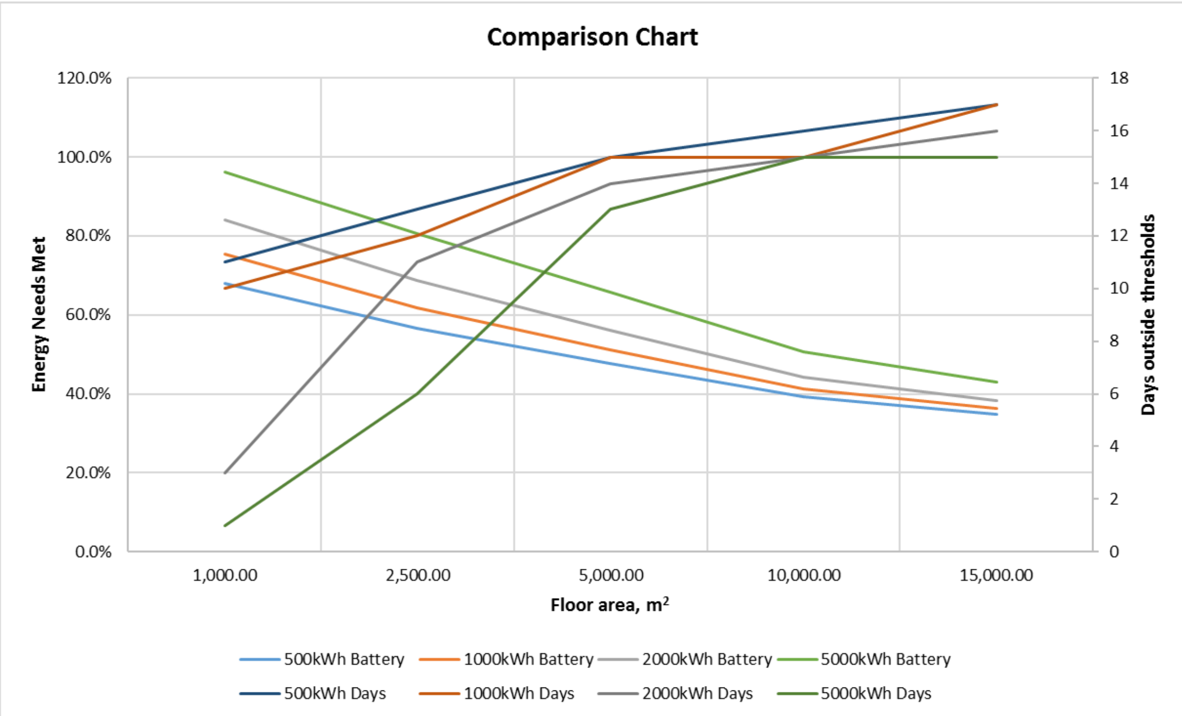



Greenhouse floor area versus Energy Requirements (1000kWH Battery)
Power per annum, MWh
12,000.00
10,000.00
8,000.00
6,000.00
4,000.00
2,000.00
0.00
1,000.00
2,500.00
5,000.00
10,000.00
15,000.00
Floor area, m2
Energy Required
Renewable Energy Used
Total Shortfall


Greenhouse floor area versus Energy Requirements (2000 kWh Battery)
Power per annum, MWh
12,000.00
10,000.00
8,000.00
6,000.00
4,000.00
2,000.00
0.00
1,000.00
2,500.00
5,000.00
10,000.00
15,000.00
Floor area, m2
Energy Required
Renewable Energy Used
Total Shortfall



Comparison of All iterations



Appendix J – Scenario 5 Results

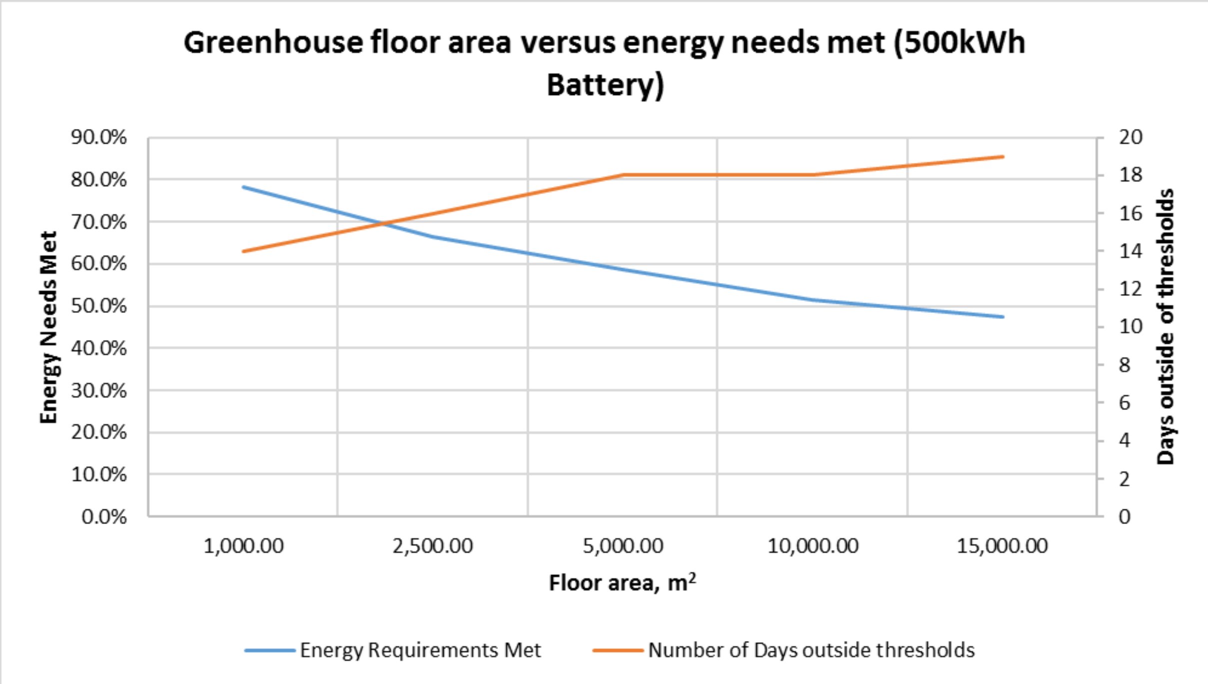
	5				
	Spill, Battery Included, No Summer Production, Single Crop (Tomatoes) (500kWh Battery)				
Critical Temperatures					
Split Crop?	No	No	No	No	No
Maximum 1	29	29	29	29	29
Minimum 1	13	13	13	13	13
Controlled Temp	26.5	26.5	26.5	26.5	26.5
Greenhouse Size					
Base Floor Area	10000	10000	10000	10000	10000
Surface Area of Glass	11808	11808	11808	11808	11808
Glass Thickness	0.015	0.015	0.015	0.015	0.015
Length	100	100	100	100	100
Width	100	100	100	100	100
Ceiling Height	4	4	4	4	4
Roof Height	2	2	2	2	2
Battery Size					
Storage Capability	500	500	500	500	500
Discharge/Charge Capability	500	500	500	500	500
Portion not able to discharge	5%	5%	5%	5%	5%
Summer Only					
No Summer Production off?	Yes	Yes	Yes	Yes	Yes
Growing Starts	1/03/2015	1/03/2015	1/03/2015	1/03/2015	1/03/2015
Growing Ends	31/10/2015	31/10/2015	31/10/2015	31/10/2015	31/10/2015
OUTPUT					
Possible Floor Area	1,000.00	2,500.00	5,000.00	10,000.00	15,000.00
No. days above critical	11.00	13.00	14.00	14.00	15.00
No. days below critical	3.00	3.00	4.00	4.00	4.00
Renewable shortfall	80.29	308.88	759.41	1,775.60	2,890.31
Energy Required	366.84	917.11	1,834.22	3,668.43	5,502.65
Diesel Used	0.00	0.00	0.00	0.00	0.00
Total Shortfall	80.29	308.88	759.41	1,775.60	2,890.31
Renewable Energy Used	286.55	608.23	1,074.80	1,892.84	2,612.34
Battery usage	135.93	163.29	173.31	179.03	183.01
Battery Discharge to town	58.59	58.59	58.59	58.59	58.59
Energy Spilled	0.00	0.00	0.00	0.00	0.00
Energy Needs Met	78.1%	66.3%	58.6%	51.6%	47.5%

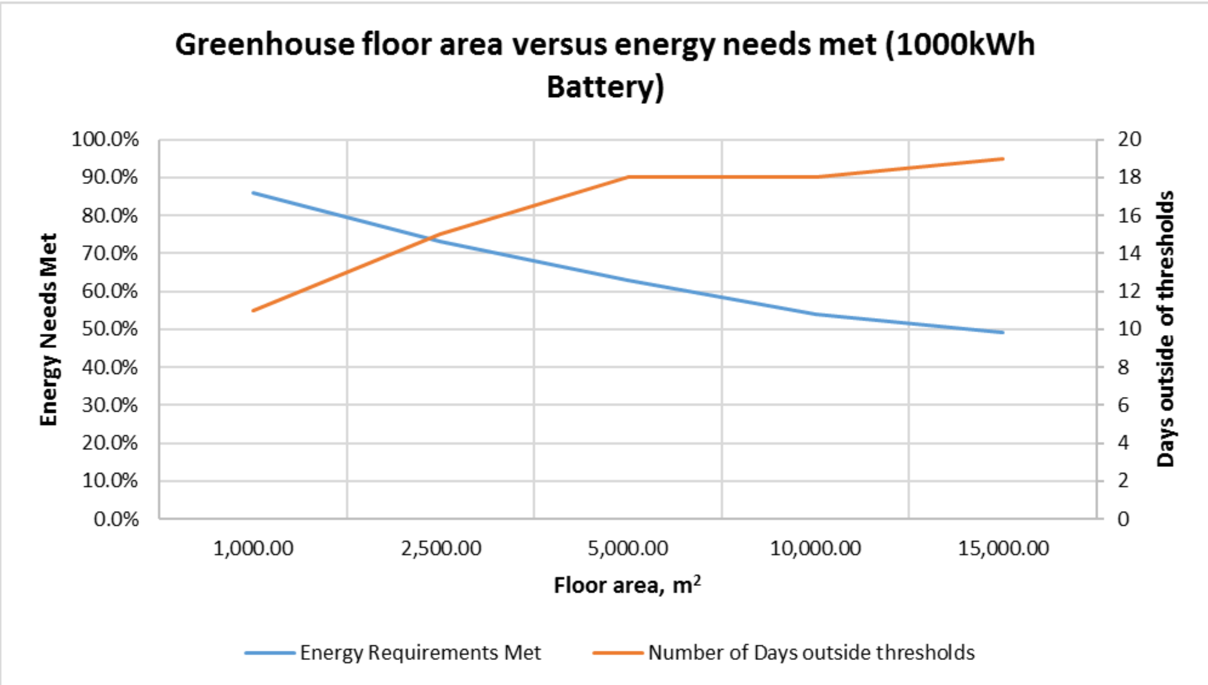
	5				
	Spill, Battery Included, No Summer Production, Single Crop (Tomatoes) (1000kWh Battery)				
Critical Temperatures					
Split Crop?	No	No	No	No	No
Maximum 1	29	29	29	29	29
Minimum 1	13	13	13	13	13
Controlled Temp	26.5	26.5	26.5	26.5	26.5
Greenhouse Size					
Base Floor Area	10000	10000	10000	10000	10000
Surface Area of Glass	11808	11808	11808	11808	11808
Glass Thickness	0.015	0.015	0.015	0.015	0.015
Length	100	100	100	100	100
Width	100	100	100	100	100
Ceiling Height	4	4	4	4	4
Roof Height	2	2	2	2	2
Battery Size					
Storage Capability	1000	1000	1000	1000	1000
Discharge/Charge Capability	1000	1000	1000	1000	1000
Portion not able to discharge	5%	5%	5%	5%	5%
Summer Only					
No Summer Production off?	Yes	Yes	Yes	Yes	Yes
Growing Starts	1/03/2015	1/03/2015	1/03/2015	1/03/2015	1/03/2015
Growing Ends	31/10/2015	31/10/2015	31/10/2015	31/10/2015	31/10/2015
OUTPUT					
Possible Floor Area	1,000.00	2,500.00	5,000.00	10,000.00	15,000.00
No. days above critical	8.00	12.00	14.00	14.00	15.00
No. days below critical	3.00	3.00	4.00	4.00	4.00
Renewable shortfall	51.37	247.57	678.52	1,687.83	2,802.08
Energy Required	366.84	917.11	1,834.22	3,668.43	5,502.65
Diesel Used	0.00	0.00	0.00	0.00	0.00
Total Shortfall	51.37	247.57	678.52	1,687.83	2,802.08
Renewable Energy Used	315.47	669.53	1,155.70	1,980.61	2,700.57
Battery usage	212.33	272.08	301.69	314.28	318.72
Battery Discharge to town	106.07	106.07	106.07	106.07	106.07
Energy Spilled	0.00	0.00	0.00	0.00	0.00
Energy Needs Met	86.0%	73.0%	63.0%	54.0%	49.1%

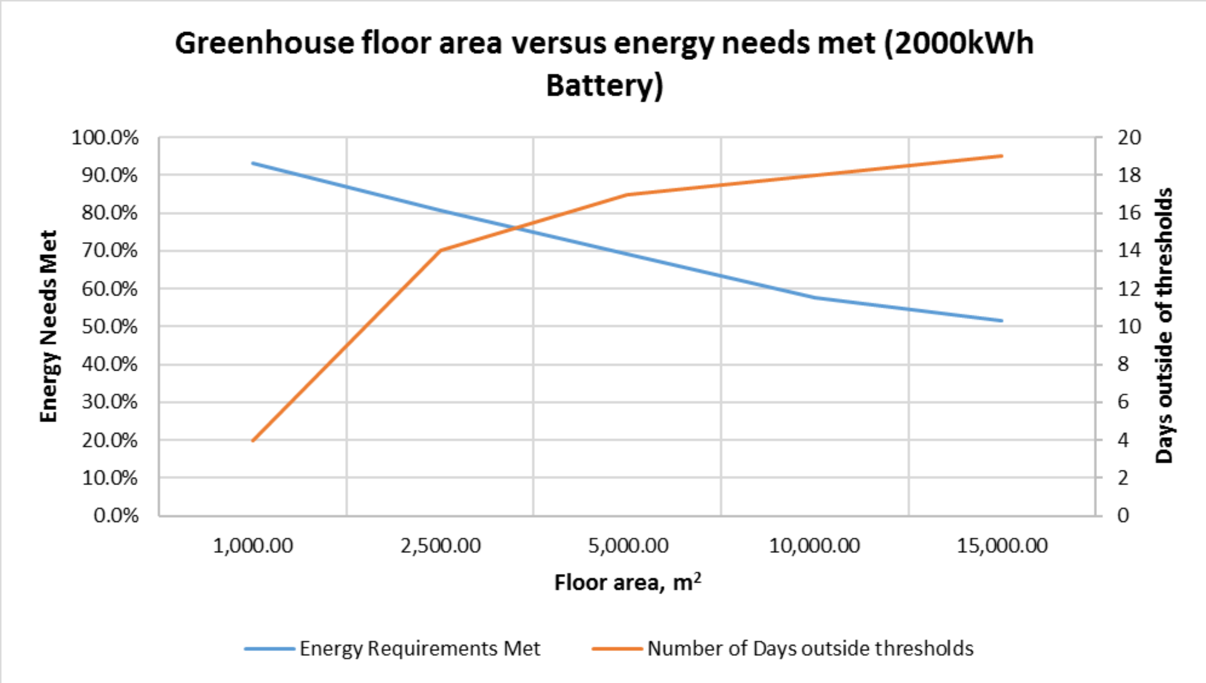
	5				
	Spill, Battery Included, No Summer Production, Single Crop (Tomatoes) (2000kWh Battery)				
Critical Temperatures					
Split Crop?	No	No	No	No	No
Maximum 1	29	29	29	29	29
Minimum 1	13	13	13	13	13
Controlled Temp	26.5	26.5	26.5	26.5	26.5
Greenhouse Size					
Base Floor Area	10000	10000	10000	10000	10000
Surface Area of Glass	11808	11808	11808	11808	11808
Glass Thickness	0.015	0.015	0.015	0.015	0.015
Length	100	100	100	100	100
Width	100	100	100	100	100
Ceiling Height	4	4	4	4	4
Roof Height	2	2	2	2	2
Battery Size					
Storage Capability	2000	2000	2000	2000	2000
Discharge/Charge Capability	2000	2000	2000	2000	2000
Portion not able to discharge	5%	5%	5%	5%	5%
Summer Only					
No Summer Production off?	Yes	Yes	Yes	Yes	Yes
Growing Starts	1/03/2015	1/03/2015	1/03/2015	1/03/2015	1/03/2015
Growing Ends	31/10/2015	31/10/2015	31/10/2015	31/10/2015	31/10/2015
OUTPUT					
Possible Floor Area	1,000.00	2,500.00	5,000.00	10,000.00	15,000.00
No. days above critical	3.00	11.00	13.00	14.00	15.00
No. days below critical	1.00	3.00	4.00	4.00	4.00
Renewable shortfall	25.05	177.64	564.74	1,548.82	2,659.92
Energy Required	366.84	917.11	1,834.22	3,668.43	5,502.65
Diesel Used	0.00	0.00	0.00	0.00	0.00
Total Shortfall	25.05	177.64	564.74	1,548.82	2,659.92
Renewable Energy Used	341.79	739.46	1,269.16	2,119.62	2,842.73
Battery usage	318.73	421.39	494.84	532.67	540.27
Battery Discharge to town	186.14	185.45	185.45	185.45	185.45
Energy Spilled	0.00	0.00	0.00	0.00	0.00
Energy Needs Met	93.2%	80.6%	69.2%	57.8%	51.7%

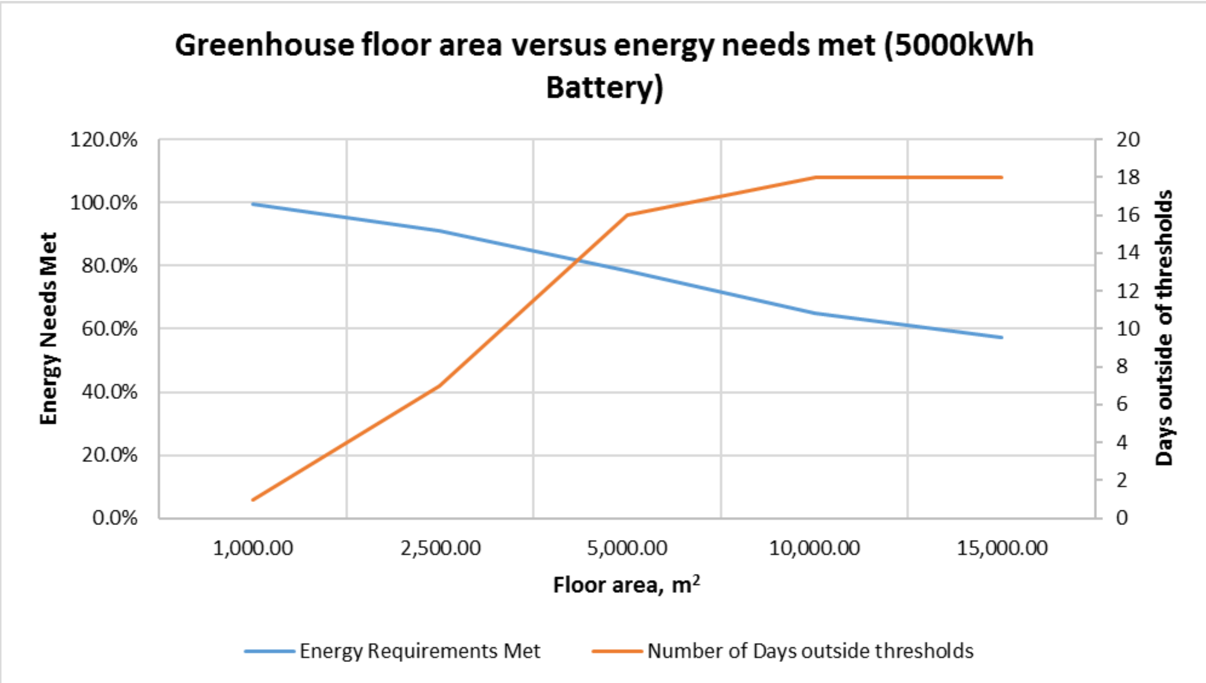
	5				
	Spill, Battery Included, No Summer Production, Single Crop (Tomatoes) (5000kWh)				
Critical Temperatures					
Split Crop?	No	No	No	No	No
Maximum 1	29	29	29	29	29
Minimum 1	13	13	13	13	13
Controlled Temp	26.5	26.5	26.5	26.5	26.5
Greenhouse Size					
Base Floor Area	10000	10000	10000	10000	10000
Surface Area of Glass	11808	11808	11808	11808	11808
Glass Thickness	0.015	0.015	0.015	0.015	0.015
Length	100	100	100	100	100
Width	100	100	100	100	100
Ceiling Height	4	4	4	4	4
Roof Height	2	2	2	2	2
Battery Size					
Storage Capability	5000	5000	5000	5000	5000
Discharge/Charge Capability	5000	5000	5000	5000	5000
Portion not able to discharge	5%	5%	5%	5%	5%
Summer Only					
No Summer Production off?	Yes	Yes	Yes	Yes	Yes
Growing Starts	1/03/2015	1/03/2015	1/03/2015	1/03/2015	1/03/2015
Growing Ends	31/10/2015	31/10/2015	31/10/2015	31/10/2015	31/10/2015
OUTPUT					
Possible Floor Area	1,000.00	2,500.00	5,000.00	10,000.00	15,000.00
No. days above critical	1.00	6.00	12.00	14.00	14.00
No. days below critical	0.00	1.00	4.00	4.00	4.00
Renewable shortfall	2.29	82.72	393.00	1,284.24	2,360.00
Energy Required	366.84	917.11	1,834.22	3,668.43	5,502.65
Diesel Used	0.00	0.00	0.00	0.00	0.00
Total Shortfall	2.29	82.72	393.00	1,284.24	2,360.00
Renewable Energy Used	364.55	834.39	1,441.21	2,384.20	3,142.65
Battery usage	518.07	693.38	843.13	973.80	1,016.74
Battery Discharge to town	362.73	362.52	362.00	362.00	362.00
Energy Spilled	0.00	0.00	0.00	0.00	0.00
Energy Needs Met	99.4%	91.0%	78.6%	65.0%	57.1%

Greenhouse Energy relationship chart

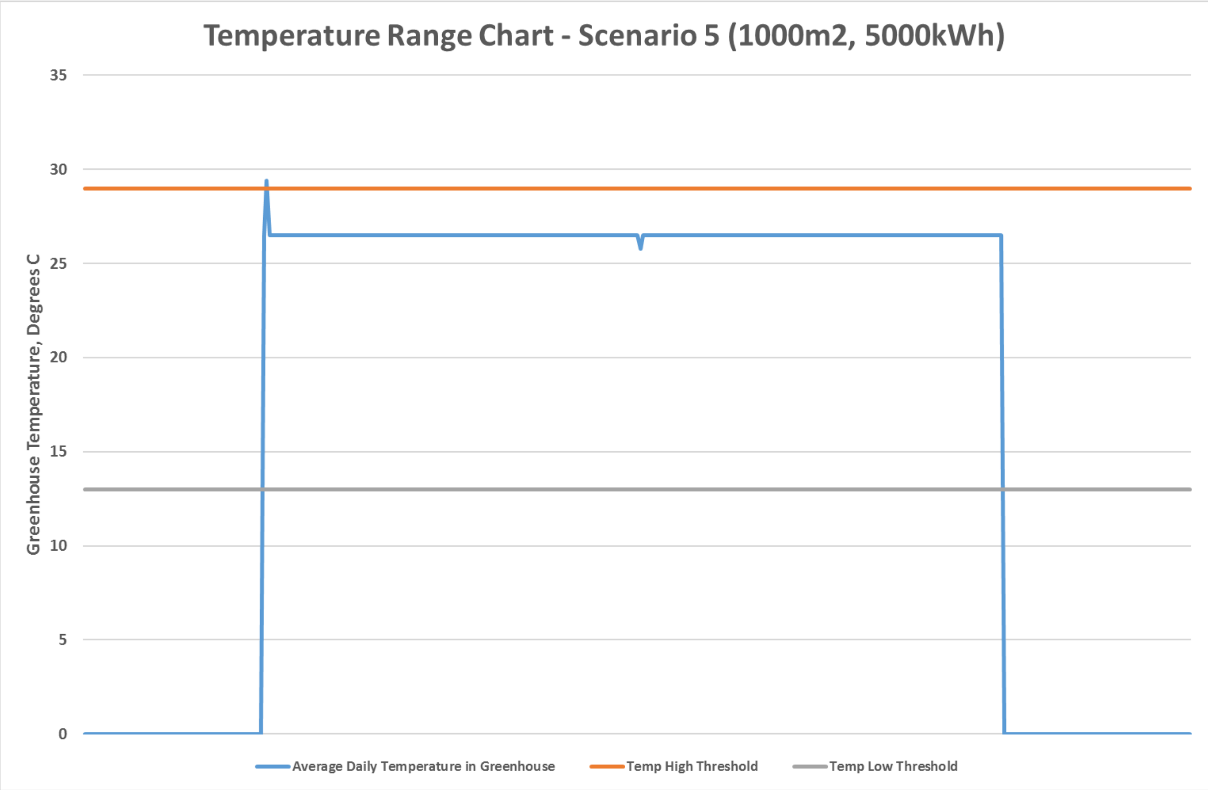




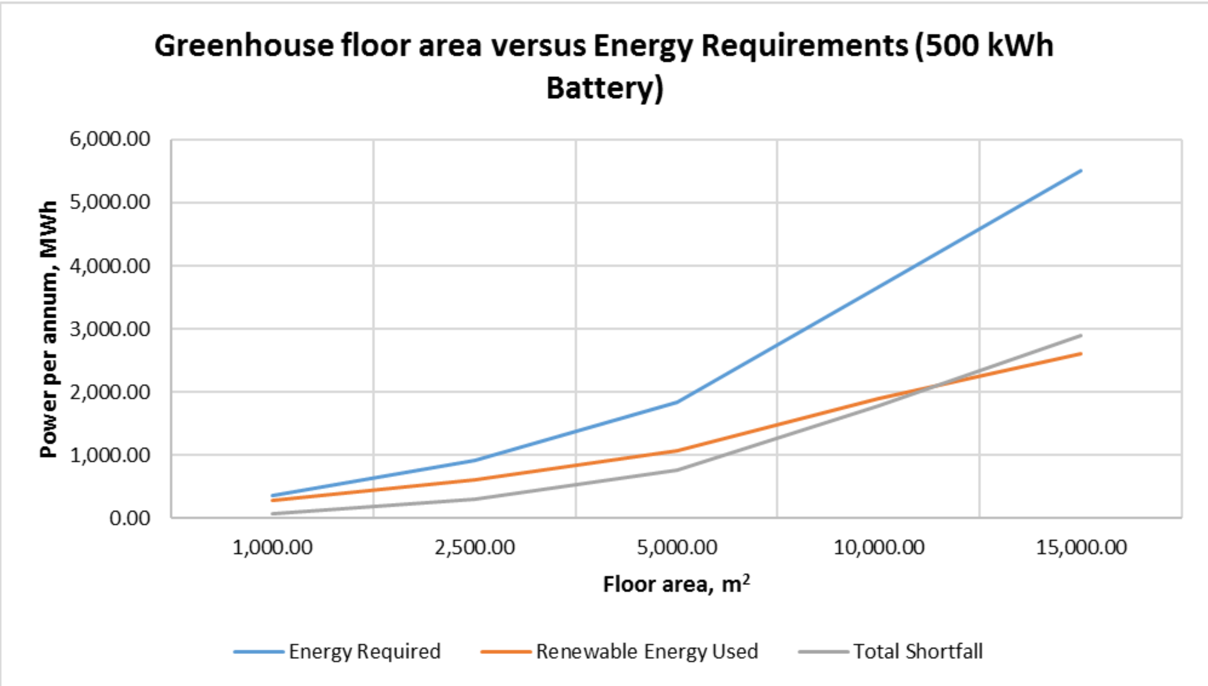

Greenhouse floor area versus energy needs met (2000kWh Battery)
Energy Needs Met
100.0%
90.0%
80.0%
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
Days outside of thresholds
20
18
16
14
12
10
8
6
4
2
0
1,000.00
2,500.00
5,000.00
10,000.00
15,000.00
Floor area, m2
Energy Requirements Met
Number of Days outside thresholds

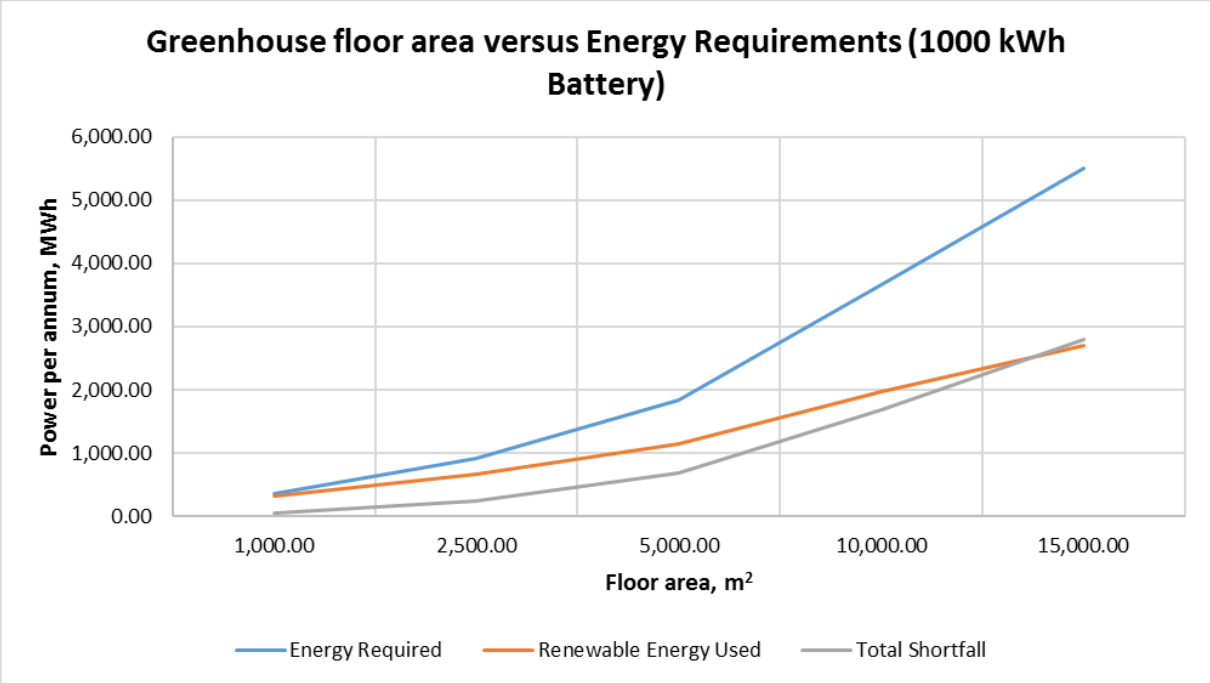

Greenhouse floor area versus energy needs met (5000kWh Battery)
Energy Needs Met
120.0%
100.0%
80.0%
60.0%
40.0%
20.0%
0.0%
Days outside of thresholds
20
18
16
14
12
10
8
6
4
2
0
1,000.00
2,500.00
5,000.00
10,000.00
15,000.00
Floor area, m2
Energy Requirements Met
Number of Days outside thresholds

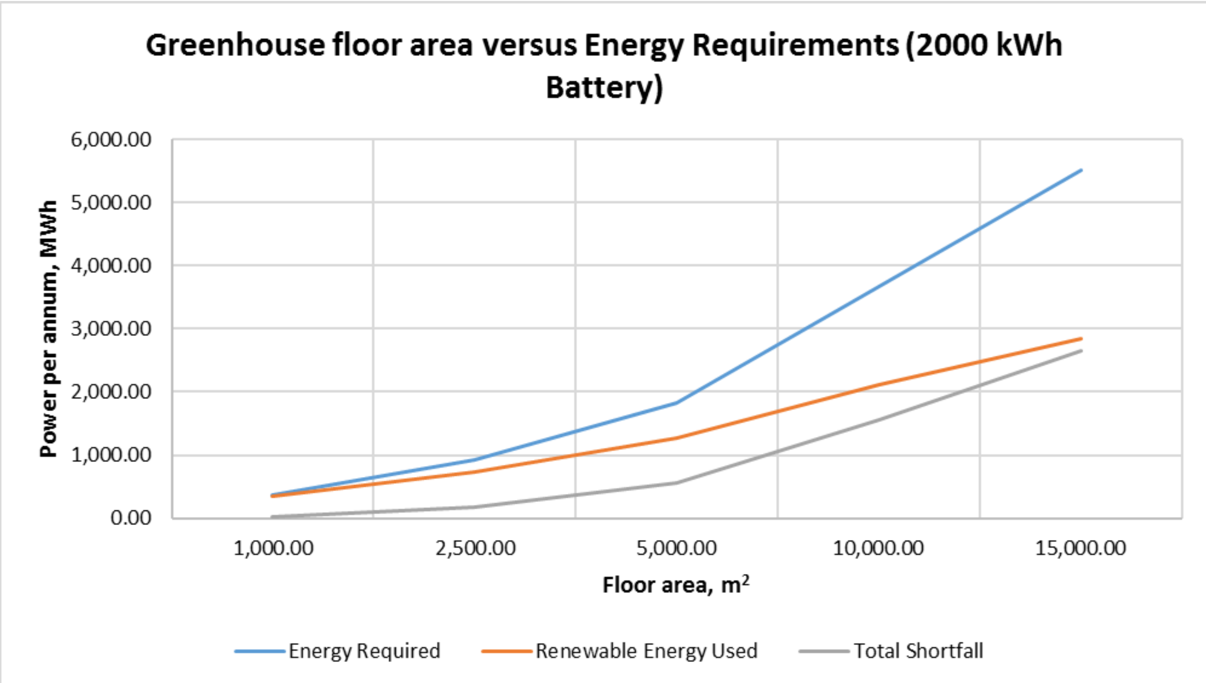
Temperature chart for chosen Scenario

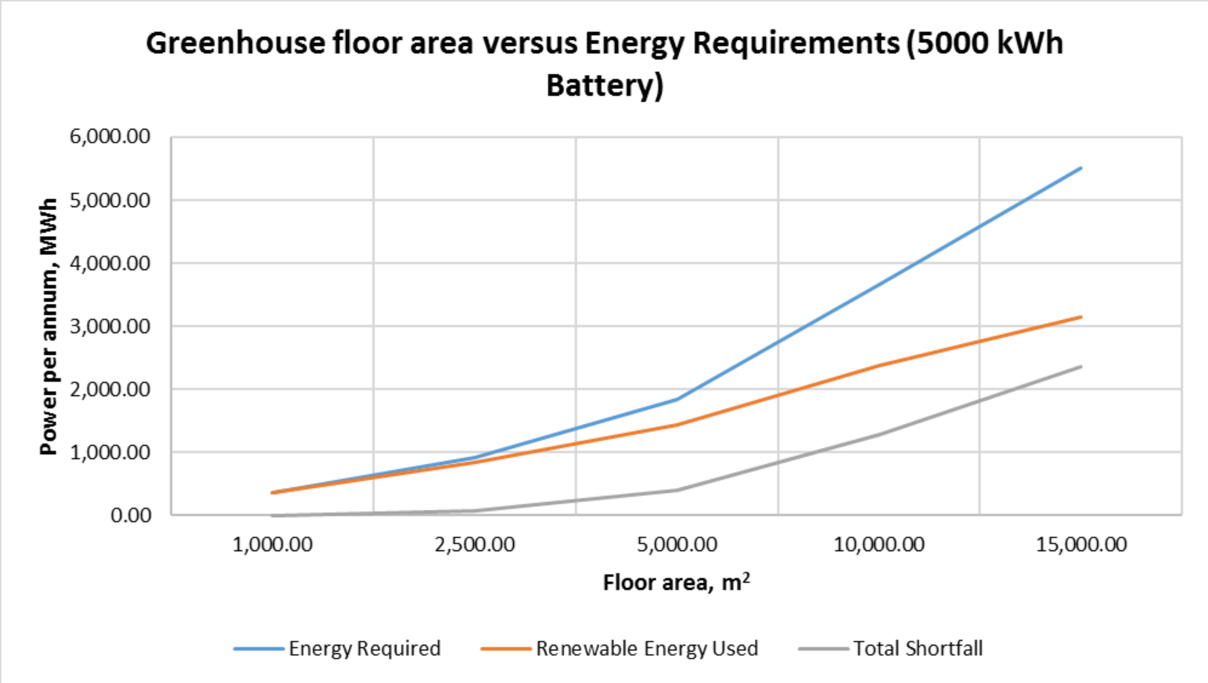


Relationship Between Energy Requirements, Floor Area and Battery Size

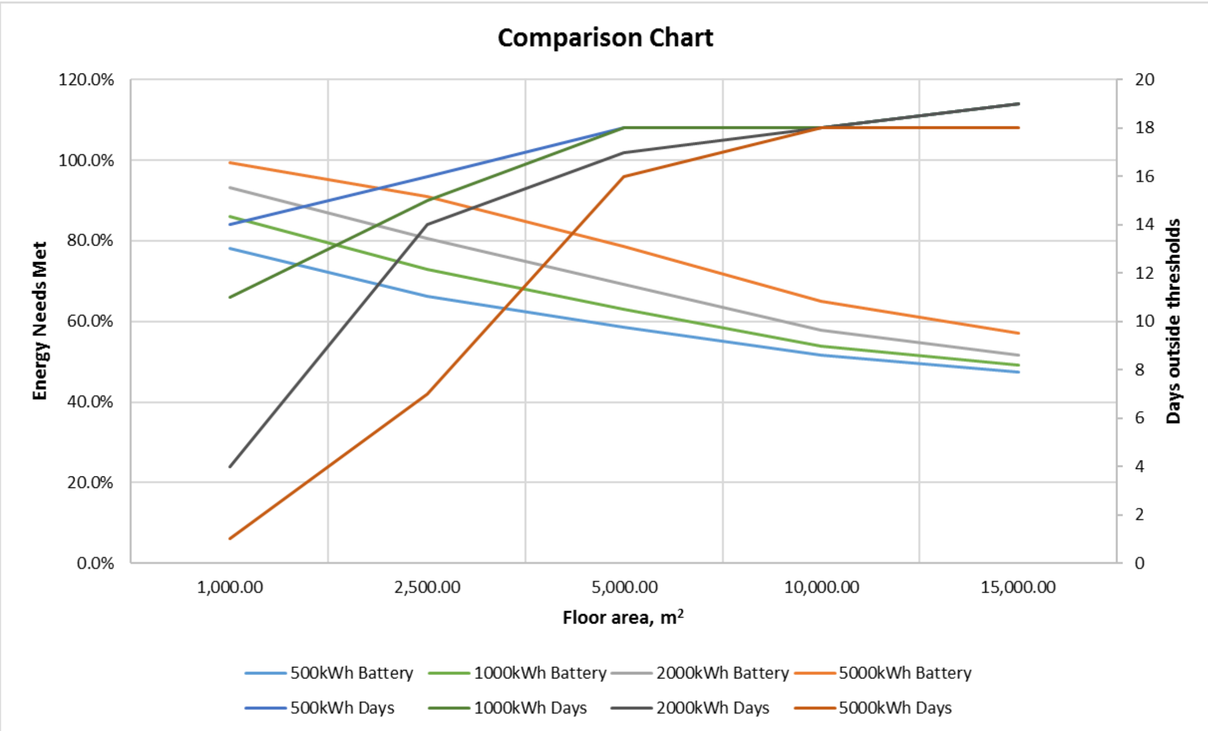



Greenhouse floor area versus Energy Requirements (1000 kWh Battery)
6,000.00
5,000.00
4,000.00
3,000.00
2,000.00
1,000.00
0.00
Power per annum, MWh
1,000.00
2,500.00
5,000.00
10,000.00
15,000.00
Floor area, m2
Energy Required
Renewable Energy Used
Total Shortfall


Greenhouse floor area versus Energy Requirements (2000 kWh Battery)
6,000.00
5,000.00
4,000.00
3,000.00
2,000.00
1,000.00
0.00
Power per annum, MWh
1,000.00
2,500.00
5,000.00
10,000.00
15,000.00
Floor area, m2
Energy Required
Renewable Energy Used
Total Shortfall



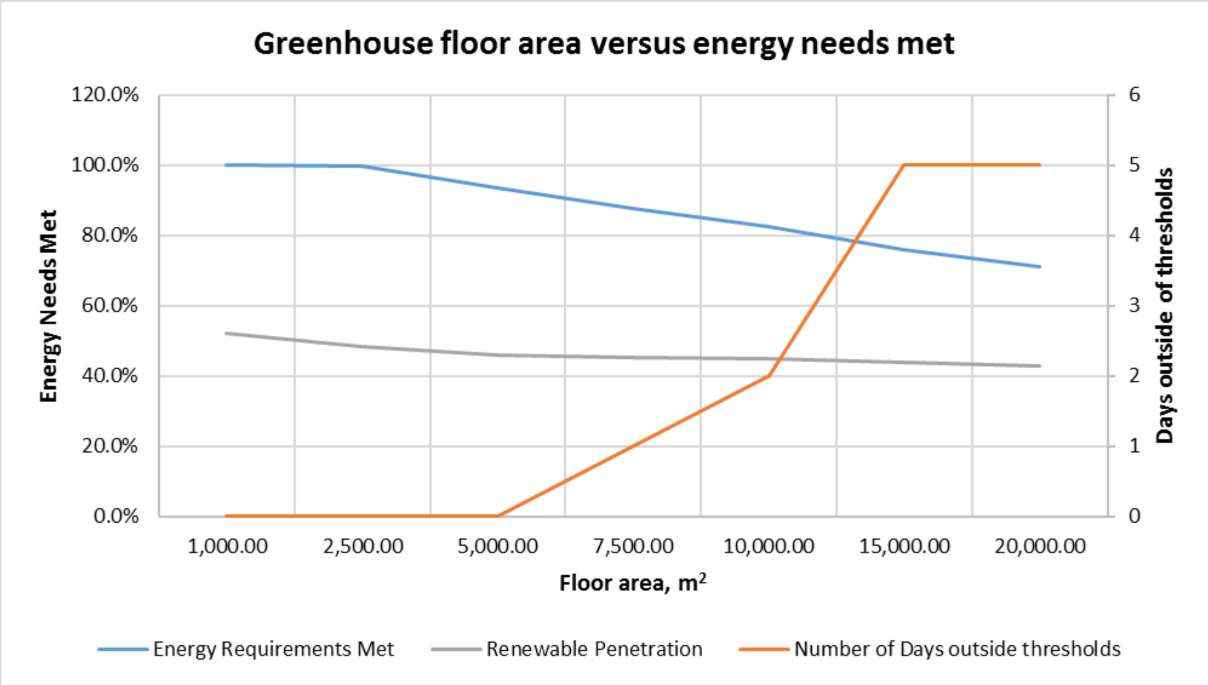
Comparison of all iterations



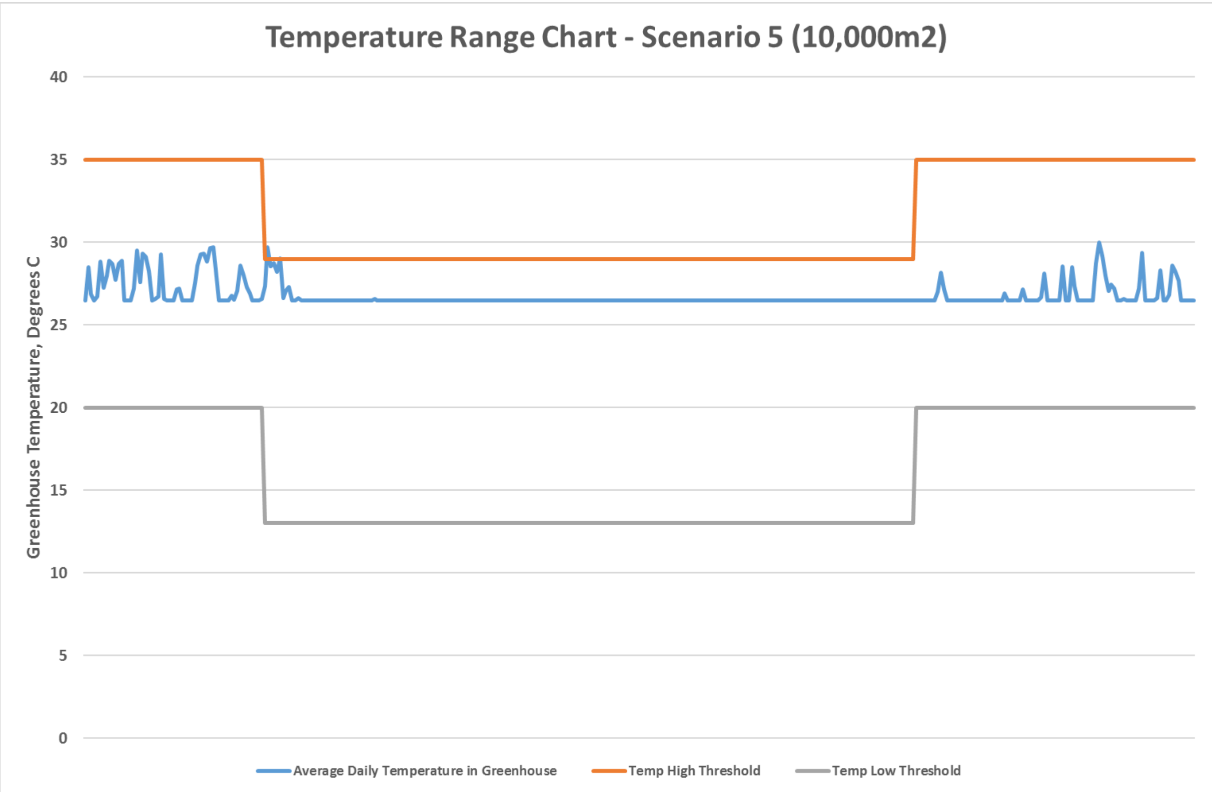
Appendix K – Scenario 6 Results

	6					
	Spill, Diesel Backup, No Battery, Split Crop (Cucumber and Tomato)					
Critical Temperatures						
Split Crop?	Yes	Yes	Yes	Yes	Yes	Yes
Maximum 1	35	35	35	35	35	35
Minimum 1	20	20	20	20	20	20
Controlled Temp 1	26.5	26.5	26.5	26.5	26.5	26.5
Growing 1 Start	1/01/2015	1/01/2015	1/01/2015	1/01/2015	1/01/2015	1/01/2015
Growing 1 End	1/03/2015	1/03/2015	1/03/2015	1/03/2015	1/03/2015	1/03/2015
Growing 2 Start	1/10/2015	1/10/2015	1/10/2015	1/10/2015	1/10/2015	1/10/2015
Growing 2 End	1/01/2016	1/01/2016	1/01/2016	1/01/2016	1/01/2016	1/01/2016
Maximum 2	29	29	29	29	29	29
Minimum 2	13	13	13	13	13	13
Controlled Temp 2	26.5	26.5	26.5	26.5	26.5	26.5
Growing 3 Start	1/03/2015	1/03/2015	1/03/2015	1/03/2015	1/03/2015	1/03/2015
Growing 3 End	1/10/2015	1/10/2015	1/10/2015	1/10/2015	1/10/2015	1/10/2015
Greenhouse Size						
Base Floor Area	10000	10000	10000	10000	10000	10000
Surface Area of Glass	11808	11808	11808	11808	11808	11808
Glass Thickness	0.015	0.015	0.015	0.015	0.015	0.015
Length	100	100	100	100	100	100
Width	100	100	100	100	100	100
Ceiling Height	4	4	4	4	4	4
Roof Height	2	2	2	2	2	2
Diesel Component						
Diesel Required?	Yes	Yes	Yes	Yes	Yes	Yes
OUTPUT						
Possible Floor Area	1,000.00	2,500.00	5,000.00	7,500.00	10,000.00	15,000.00
No. days above critical	0.00	0.00	0.00	1.00	2.00	5.00
No. days below critical	0.00	0.00	0.00	0.00	0.00	0.00
Renewable shortfall	364.86	989.72	2,173.36	3,460.82	4,807.54	7,629.59
Energy Required	761.88	1,904.71	3,809.42	5,714.14	7,618.85	11,428.27
Diesel Used	364.86	983.88	1,930.41	2,745.58	3,475.87	4,855.67
Total Shortfall	0.00	5.83	242.94	715.25	1,331.66	2,773.92
Renewable Energy Used	397.02	915.00	1,636.07	2,253.31	2,811.31	3,798.68
Energy Needs Met	100.0%	99.7%	93.6%	87.5%	82.5%	75.7%
Renewable Penetration	52.1%	48.2%	45.9%	45.1%	44.7%	43.9%

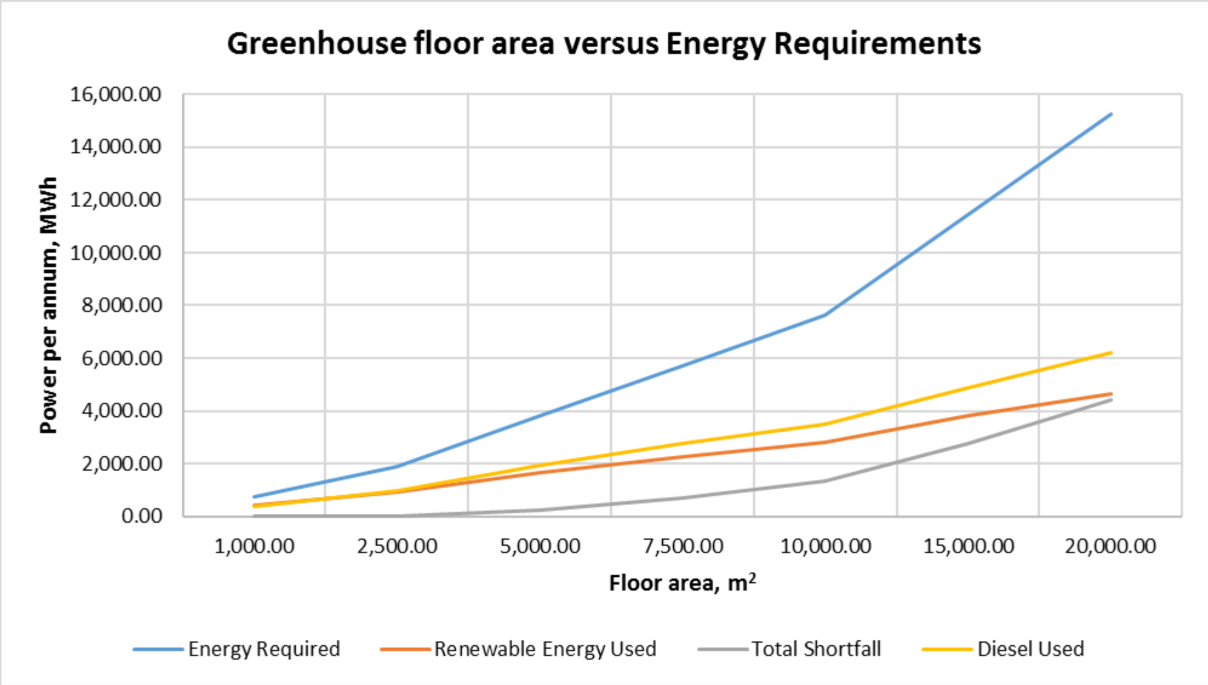
Greenhouse Energy Relationship chart



Temperature Range Chart for Chosen Scenario



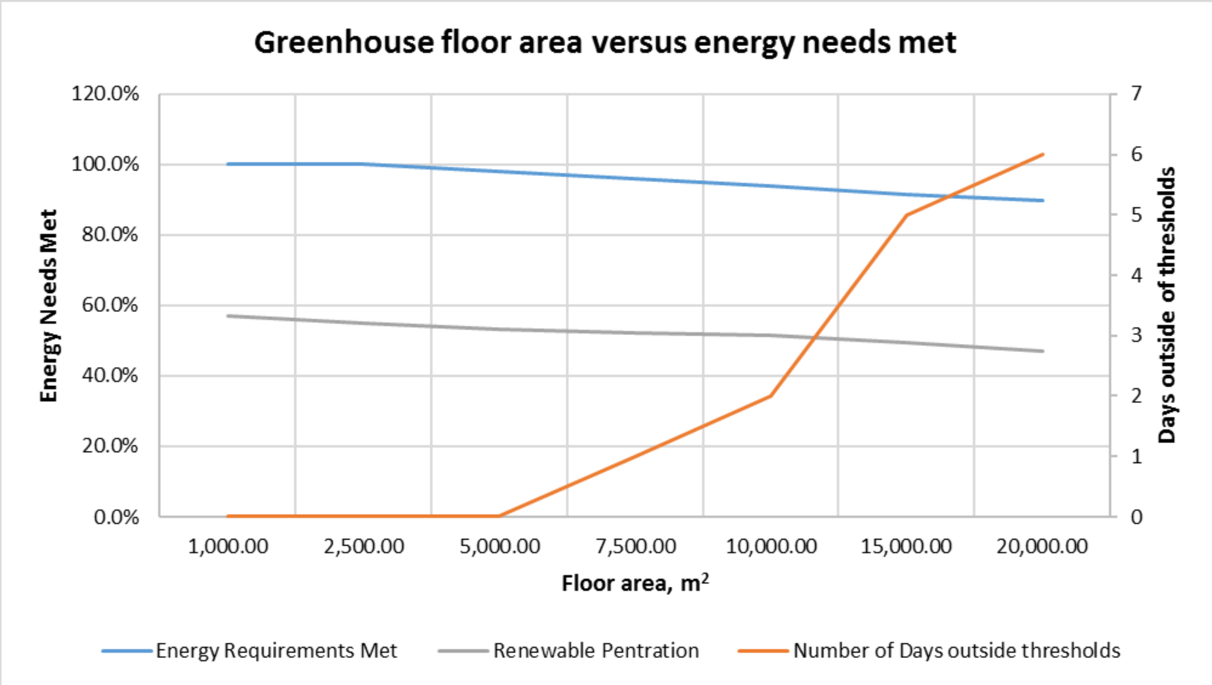
Relationship between Energy Requirements and Floor Area



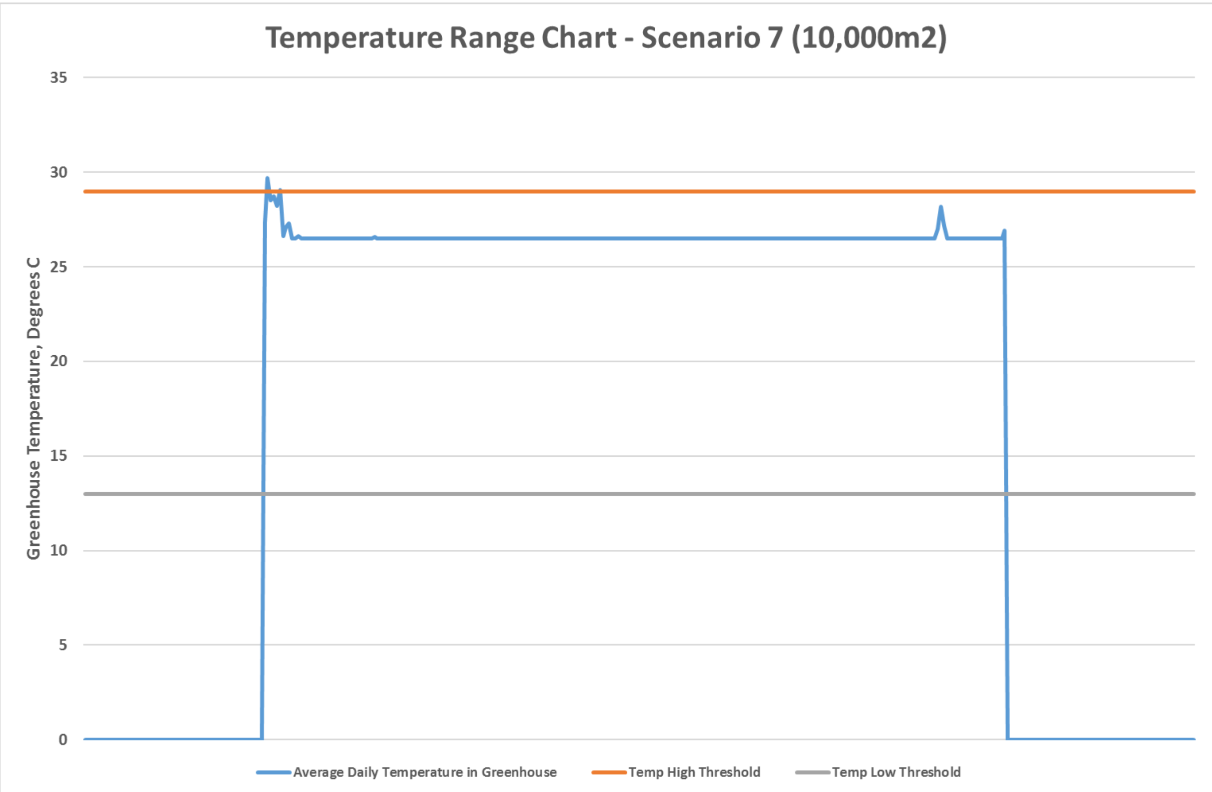
Appendix L – Scenario 7 Results

	7					
	Spill, Diesel Backup, No Battery, Summer Production Only, Single Crop (Tomato)					
Critical Temperatures						
Split Crop?	No	No	No	No	No	No
Maximum 1	29	29	29	29	29	29
Minimum 1	13	13	13	13	13	13
Controlled Temp	26.5	26.5	26.5	26.5	26.5	26.5
Greenhouse Size						
Base Floor Area	10000	10000	10000	10000	10000	10000
Surface Area of Glass	11808	11808	11808	11808	11808	11808
Glass Thickness	0.015	0.015	0.015	0.015	0.015	0.015
Length	100	100	100	100	100	100
Width	100	100	100	100	100	100
Ceiling Height	4	4	4	4	4	4
Roof Height	2	2	2	2	2	2
Diesel Component						
Diesel Required?	Yes	Yes	Yes	Yes	Yes	Yes
Summer Only						
No Summer Production off?	Yes	Yes	Yes	Yes	Yes	Yes
Growing Starts	1/03/2015	1/03/2015	1/03/2015	1/03/2015	1/03/2015	1/03/2015
Growing Ends	31/10/2015	31/10/2015	31/10/2015	31/10/2015	31/10/2015	31/10/2015
OUTPUT						
Possible Floor Area	1,000.00	2,500.00	5,000.00	7,500.00	10,000.00	15,000.00
No. days above critical temp	0.00	0.00	0.00	1.00	2.00	5.00
No. days below critical temp	0.00	0.00	0.00	0.00	0.00	0.00
Renewable shortfall	157.63	413.58	874.13	1,372.10	1,896.04	3,014.74
Energy Required	366.84	917.11	1,834.22	2,751.32	3,668.43	5,502.65
Diesel Used	157.63	413.50	838.07	1,257.32	1,677.96	2,553.65
Total Shortfall	0.00	0.09	36.07	114.78	218.08	461.08
Renewable Energy Used	209.21	503.52	960.08	1,379.23	1,772.40	2,487.91
Energy Needs Met	100.0%	100.0%	98.0%	95.8%	94.1%	91.6%
Renewable Penetration	57.0%	54.9%	53.4%	52.3%	51.4%	49.3%

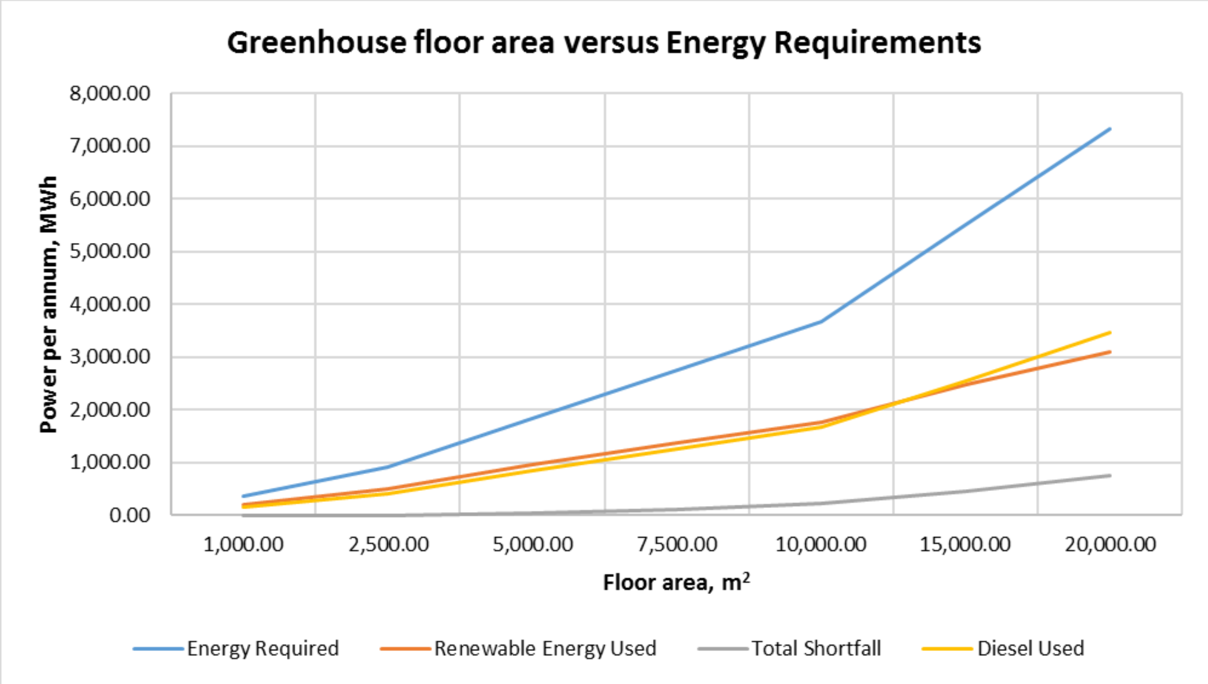
Greenhouse Energy Relationship Chart



Temperature Range Chart for chosen scenario



Relationship between Energy Requirements and Floor Area



Appendix M – Scenario 8 Results

	8				
	Spill, Battery Included, Diesel Backup, Split Crop (Cucumbers and Tomatoes) (500kWh Battery)				
Critical Temperatures					
Split Crop?	Yes	Yes	Yes	Yes	Yes
Maximum 1	35	35	35	35	35
Minimum 1	20	20	20	20	20
Controlled Temp 1	26.5	26.5	26.5	26.5	26.5
Growing 1 Start	1/01/2015	1/01/2015	1/01/2015	1/01/2015	1/01/2015
Growing 1 End	1/03/2015	1/03/2015	1/03/2015	1/03/2015	1/03/2015
Growing 2 Start	1/10/2015	1/10/2015	1/10/2015	1/10/2015	1/10/2015
Growing 2 End	1/01/2016	1/01/2016	1/01/2016	1/01/2016	1/01/2016
Maximum 2	29	29	29	29	29
Minimum 2	13	13	13	13	13
Controlled Temp 2	26.5	26.5	26.5	26.5	26.5
Growing 3 Start	1/03/2015	1/03/2015	1/03/2015	1/03/2015	1/03/2015
Growing 3 End	1/10/2015	1/10/2015	1/10/2015	1/10/2015	1/10/2015
Greenhouse Size					
Base Floor Area	10000	10000	10000	10000	10000
Surface Area of Glass	11808	11808	11808	11808	11808
Glass Thickness	0.015	0.015	0.015	0.015	0.015
Length	100	100	100	100	100
Width	100	100	100	100	100
Ceiling Height	4	4	4	4	4
Roof Height	2	2	2	2	2
Battery Size					
Storage Capability	500	500	500	500	500
Discharge/Charge Capability	500	500	500	500	500
Portion not able to discharge	5%	5%	5%	5%	5%
Diesel Component					
Diesel Required?	Yes	Yes	Yes	Yes	Yes
OUTPUT					
Possible Floor Area	1,000.00	2,500.00	5,000.00	10,000.00	15,000.00
No. days above critical temp	0.00	0.00	0.00	2.00	5.00
No. days below critical temp	0.00	0.00	0.00	0.00	0.00
Renewable shortfall	243.76	827.09	1,995.80	4,620.19	7,436.47
Energy Required	761.88	1,904.71	3,809.42	7,618.85	11,428.27
Diesel Used	243.76	821.26	1,756.65	3,293.28	4,667.19
Total Shortfall	0.00	5.83	239.15	1,326.91	2,769.28
Renewable Energy Used	518.13	1,077.62	1,813.62	2,998.66	3,991.80
Battery usage	121.11	162.62	177.56	187.35	193.12
Energy Needs Met	100.0%	99.7%	93.7%	82.6%	75.8%

Renewable Penetration	68.0%	56.8%	50.8%	47.7%	46.1%

	8				
	Spill, Battery Included, Diesel Backup, Split Crop (Cucumbers and Tomatoes) (1000kWh Battery))				
Critical Temperatures					
Split Crop?	Yes	Yes	Yes	Yes	Yes
Maximum 1	35	35	35	35	35
Minimum 1	20	20	20	20	20
Controlled Temp1	26.5	26.5	26.5	26.5	26.5
Growing 1 Start	1/01/2015	1/01/2015	1/01/2015	1/01/2015	1/01/2015
Growing 1 End	1/03/2015	1/03/2015	1/03/2015	1/03/2015	1/03/2015
Growing 2 Start	1/10/2015	1/10/2015	1/10/2015	1/10/2015	1/10/2015
Growing 2 End	1/01/2016	1/01/2016	1/01/2016	1/01/2016	1/01/2016
Maximum 2	29	29	29	29	29
Minimum 2	13	13	13	13	13
Controlled Temp 2	26.5	26.5	26.5	26.5	26.5
Growing 3 Start	1/03/2015	1/03/2015	1/03/2015	1/03/2015	1/03/2015
Growing 3 End	1/10/2015	1/10/2015	1/10/2015	1/10/2015	1/10/2015
Greenhouse Size					
Base Floor Area	10000	10000	10000	10000	10000
Surface Area of Glass	11808	11808	11808	11808	11808
Glass Thickness	0.015	0.015	0.015	0.015	0.015
Length	100	100	100	100	100
Width	100	100	100	100	100
Ceiling Height	4	4	4	4	4
Roof Height	2	2	2	2	2
Battery Size					
Storage Capability	1000	1000	1000	1000	1000
Discharge/Charge Capability	1000	1000	1000	1000	1000
Portion not able to discharge	5%	5%	5%	5%	5%
Diesel Component					
Diesel Required?	Yes	Yes	Yes	Yes	Yes
OUTPUT					
Possible Floor Area	1,000.00	2,500.00	5,000.00	10,000.00	15,000.00
No. days above critical temp	0.00	0.00	0.00	2.00	5.00
No. days below critical temp	0.00	0.00	0.00	0.00	0.00
Renewable shortfall	186.98	726.51	1,864.87	4,478.67	7,290.82
Energy Required	761.88	1,904.71	3,809.42	7,618.85	11,428.27
Diesel Used	186.98	720.68	1,628.31	3,155.61	4,525.90
Total Shortfall	0.00	5.83	236.55	1,323.06	2,764.92
Renewable Energy Used	574.91	1,178.20	1,944.56	3,140.18	4,137.45
Battery usage	177.89	263.20	308.49	328.87	338.77
Energy Needs Met	100.0%	99.7%	93.8%	82.6%	75.8%

Renewable Penetration	75.5%	62.0%	54.4%	49.9%	47.8%

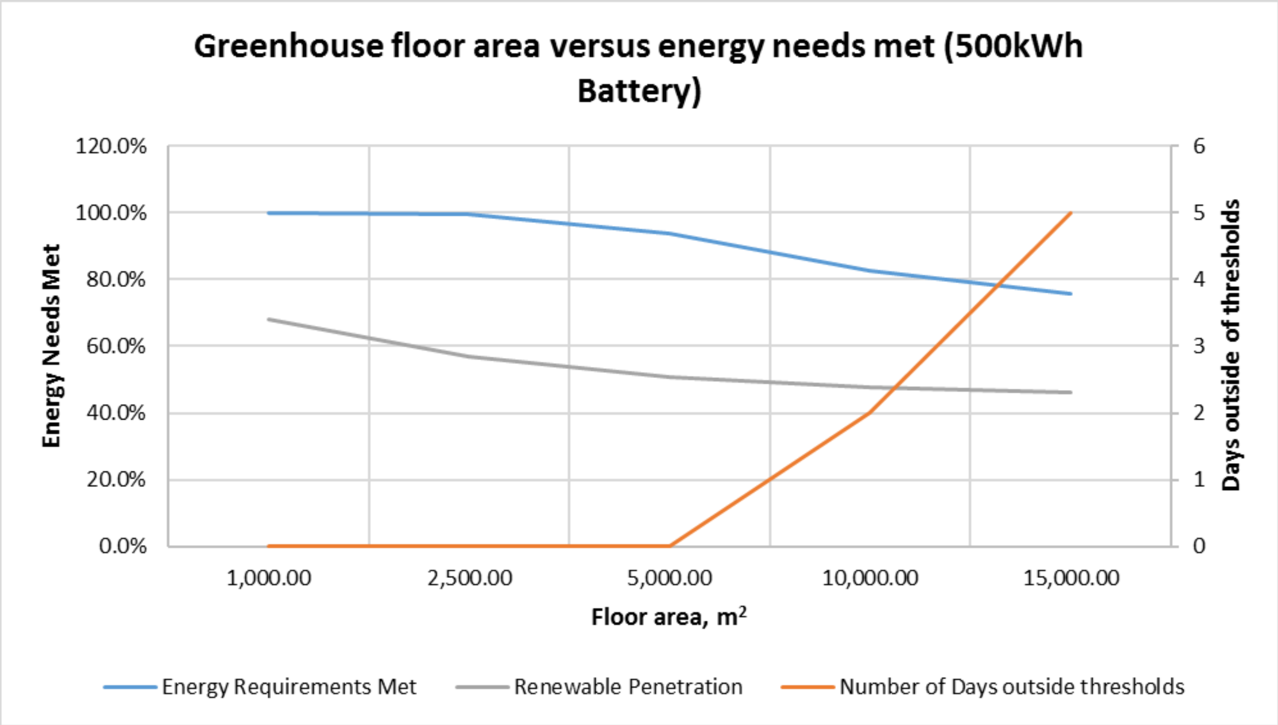
	8				
	Spill, Battery Included, Diesel Backup, Split Crop (Cucumbers and Tomatoes) (2000kWh Battery)				
Critical Temperatures					
Split Crop?	Yes	Yes	Yes	Yes	Yes
Maximum 1	35	35	35	35	35
Minimum 1	20	20	20	20	20
Controlled Temperature 1	26.5	26.5	26.5	26.5	26.5
Growing 1 Start	1/01/2015	1/01/2015	1/01/2015	1/01/2015	1/01/2015
Growing 1 End	1/03/2015	1/03/2015	1/03/2015	1/03/2015	1/03/2015
Growing 2 Start	1/10/2015	1/10/2015	1/10/2015	1/10/2015	1/10/2015
Growing 2 End	1/01/2016	1/01/2016	1/01/2016	1/01/2016	1/01/2016
Maximum 2	29	29	29	29	29
Minimum 2	13	13	13	13	13
Controlled Temperature High 2	26.5	26.5	26.5	26.5	26.5
Growing 3 Start	1/03/2015	1/03/2015	1/03/2015	1/03/2015	1/03/2015
Growing 3 End	1/10/2015	1/10/2015	1/10/2015	1/10/2015	1/10/2015
Greenhouse Size					
Base Floor Area	10000	10000	10000	10000	10000
Surface Area of Glass	11808	11808	11808	11808	11808
Glass Thickness	0.015	0.015	0.015	0.015	0.015
Length	100	100	100	100	100
Width	100	100	100	100	100
Ceiling Height	4	4	4	4	4
Roof Height	2	2	2	2	2
Battery Size					
Storage Capability	2000	2000	2000	2000	2000
Discharge/Charge Capability	2000	2000	2000	2000	2000
Portion not able to discharge	5%	5%	5%	5%	5%
Diesel Component					
Diesel Required?	Yes	Yes	Yes	Yes	Yes
OUTPUT					
Possible Floor Area	1,000.00	2,500.00	5,000.00	10,000.00	15,000.00
No. days above critical temp	0.00	0.00	0.00	2.00	5.00
No. days below critical temp	0.00	0.00	0.00	0.00	0.00
Renewable shortfall	120.61	594.30	1,669.51	4,244.19	7,048.28
Energy Required	761.88	1,904.71	3,809.42	7,618.85	11,428.27
Diesel Used	120.61	588.64	1,437.17	2,929.24	4,295.52
Total Shortfall	0.00	5.67	232.34	1,314.94	2,752.76
Renewable Energy Used	641.27	1,310.41	2,139.91	3,374.66	4,379.99
Battery usage	244.25	395.41	503.85	563.35	581.31

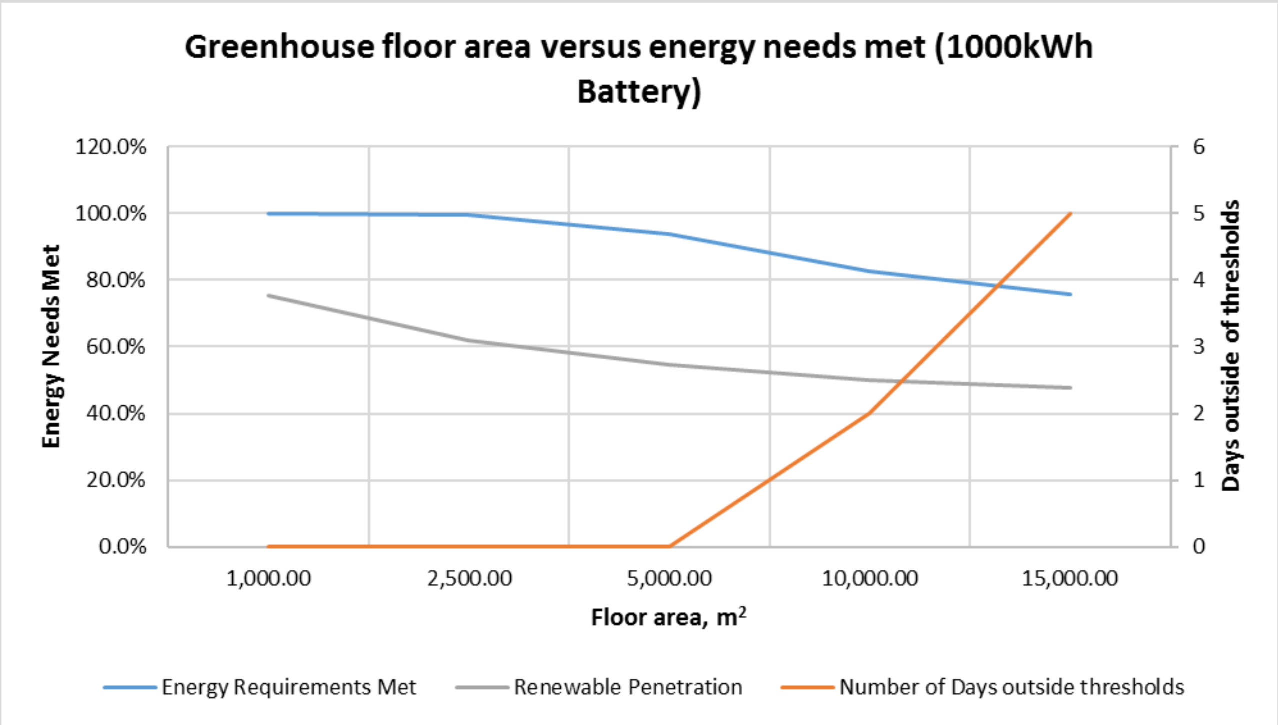
Energy Needs Met	100.0%	99.7%	93.9%	82.7%	75.9%
Renewable Penetration	84.2%	69.0%	59.8%	53.5%	50.5%

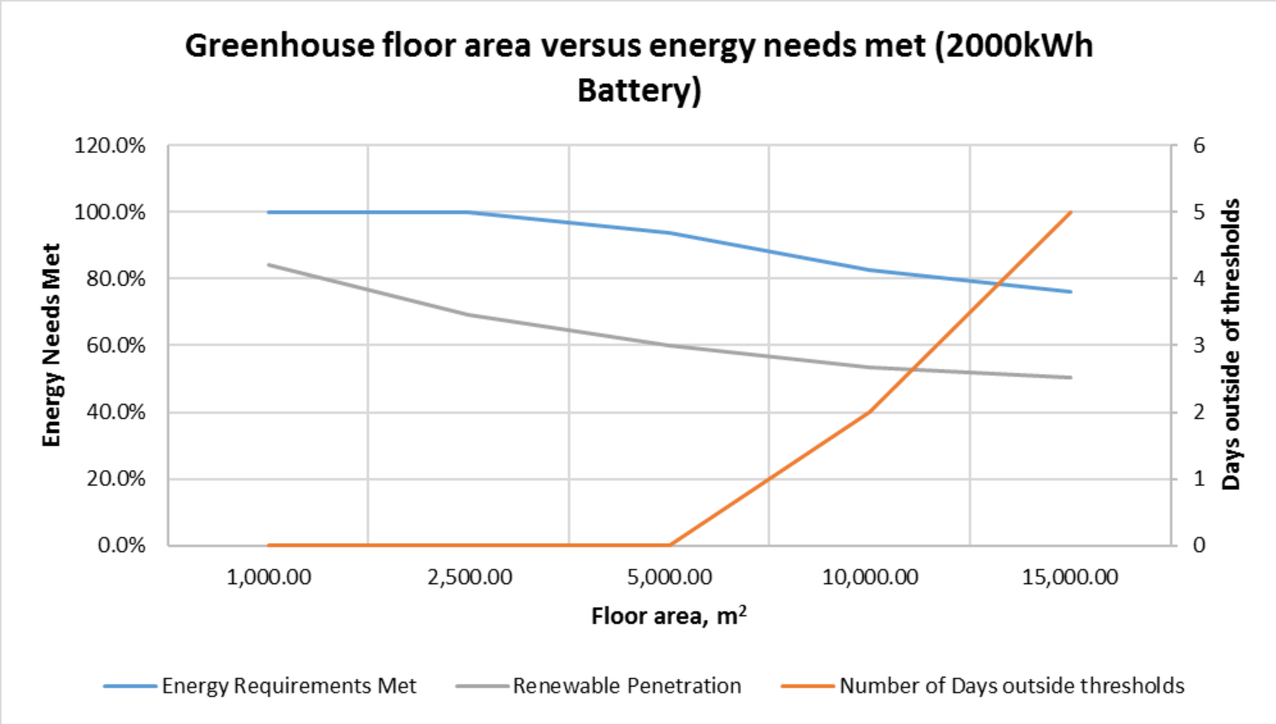
	8				
	Spill, Battery Included, Diesel Backup, Split Crop (Cucumbers and Tomatoes) (5000kWh)				
Critical Temperatures					
Split Crop?	Yes	Yes	Yes	Yes	Yes
Maximum 1	35	35	35	35	35
Minimum 1	20	20	20	20	20
Controlled Temperature 1	26.5	26.5	26.5	26.5	26.5
Growing 1 Start	1/01/2015	1/01/2015	1/01/2015	1/01/2015	1/01/2015
Growing 1 End	1/03/2015	1/03/2015	1/03/2015	1/03/2015	1/03/2015
Growing 2 Start	1/10/2015	1/10/2015	1/10/2015	1/10/2015	1/10/2015
Growing 2 End	1/01/2016	1/01/2016	1/01/2016	1/01/2016	1/01/2016
Maximum 2	29	29	29	29	29
Minimum 2	13	13	13	13	13
Controlled Temperature 2	26.5	26.5	26.5	26.5	26.5
Growing 3 Start	1/03/2015	1/03/2015	1/03/2015	1/03/2015	1/03/2015
Growing 3 End	1/10/2015	1/10/2015	1/10/2015	1/10/2015	1/10/2015
Greenhouse Size					
Base Floor Area	10000	10000	10000	10000	10000
Surface Area of Glass	11808	11808	11808	11808	11808
Glass Thickness	0.015	0.015	0.015	0.015	0.015
Length	100	100	100	100	100
Width	100	100	100	100	100
Ceiling Height	4	4	4	4	4
Roof Height	2	2	2	2	2
Battery Size					
Storage Capability	5000	5000	5000	5000	5000
Discharge/Charge Capability	5000	5000	5000	5000	5000
Portion not able to discharge	5%	5%	5%	5%	5%
Diesel Component					
Diesel Required?	Yes	Yes	Yes	Yes	Yes
OUTPUT					
Possible Floor Area	1,000.00	2,500.00	5,000.00	10,000.00	15,000.00
No. days above critical temp	0.00	0.00	0.00	1.00	4.00
No. days below critical temp	0.00	0.00	0.00	0.00	0.00
Renewable shortfall	28.48	369.98	1,307.53	3,751.74	6,506.99
Energy Required	761.88	1,904.71	3,809.42	7,618.85	11,428.27
Diesel Used	28.48	365.81	1,084.81	2,484.11	3,807.69
Total Shortfall	0.00	4.18	222.72	1,267.62	2,699.31
Renewable Energy Used	733.40	1,534.73	2,501.89	3,867.11	4,921.28

Battery usage	336.38	619.73	865.82	1,055.80	1,122.60
Energy Needs Met	100.0%	99.8%	94.2%	83.4%	76.4%
Renewable Penetration	96.3%	80.8%	69.8%	60.9%	56.4%

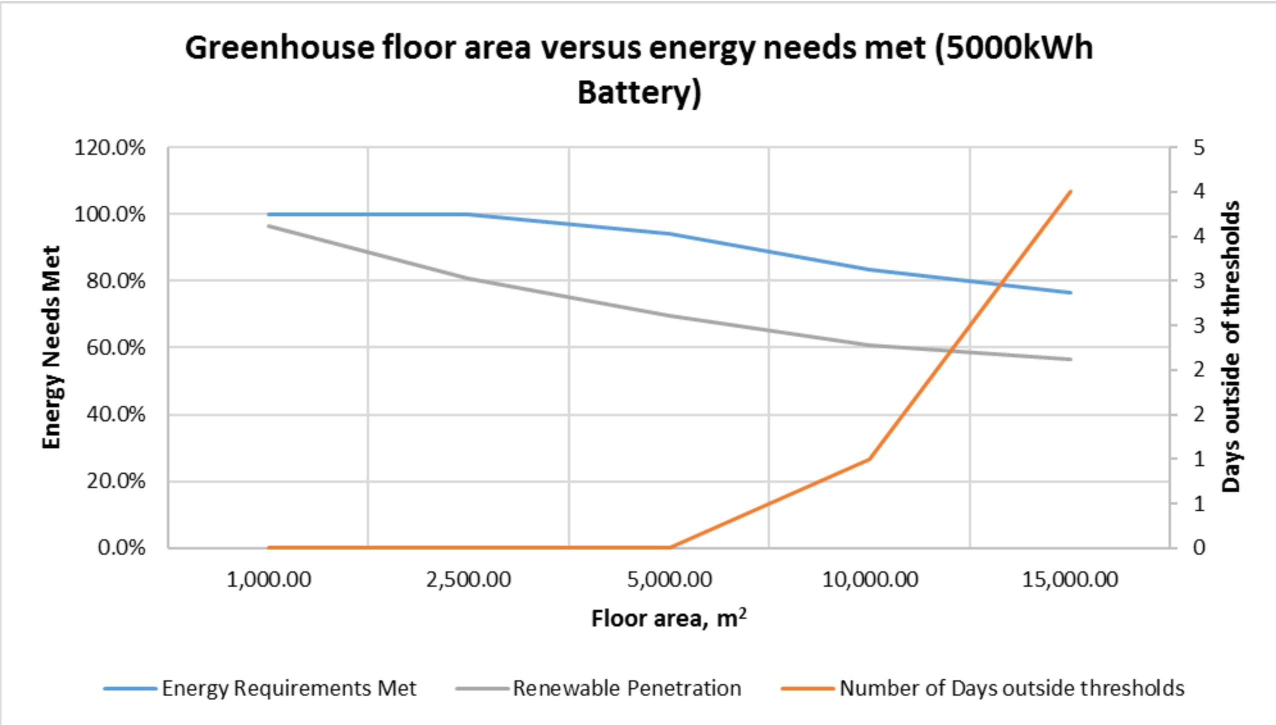
Greenhouse Energy Relationship Chart





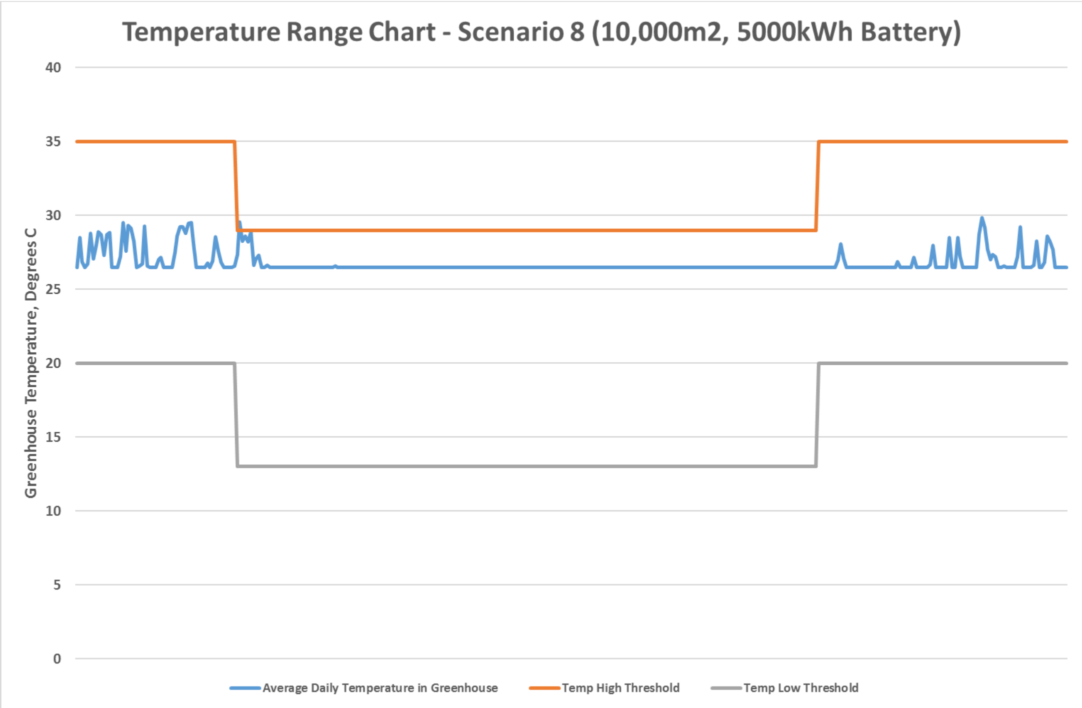


Greenhouse floor area versus energy needs met (2000kWh Battery)
Energy Needs Met
Days outside of thresholds
120.0%
100.0%
80.0%
60.0%
40.0%
20.0%
0.0%
6
5
4
3
2
1
0
1,000.00
2,500.00
5,000.00
10,000.00
15,000.00
Floor area, m2
Energy Requirements Met
Renewable Penetration
Number of Days outside thresholds

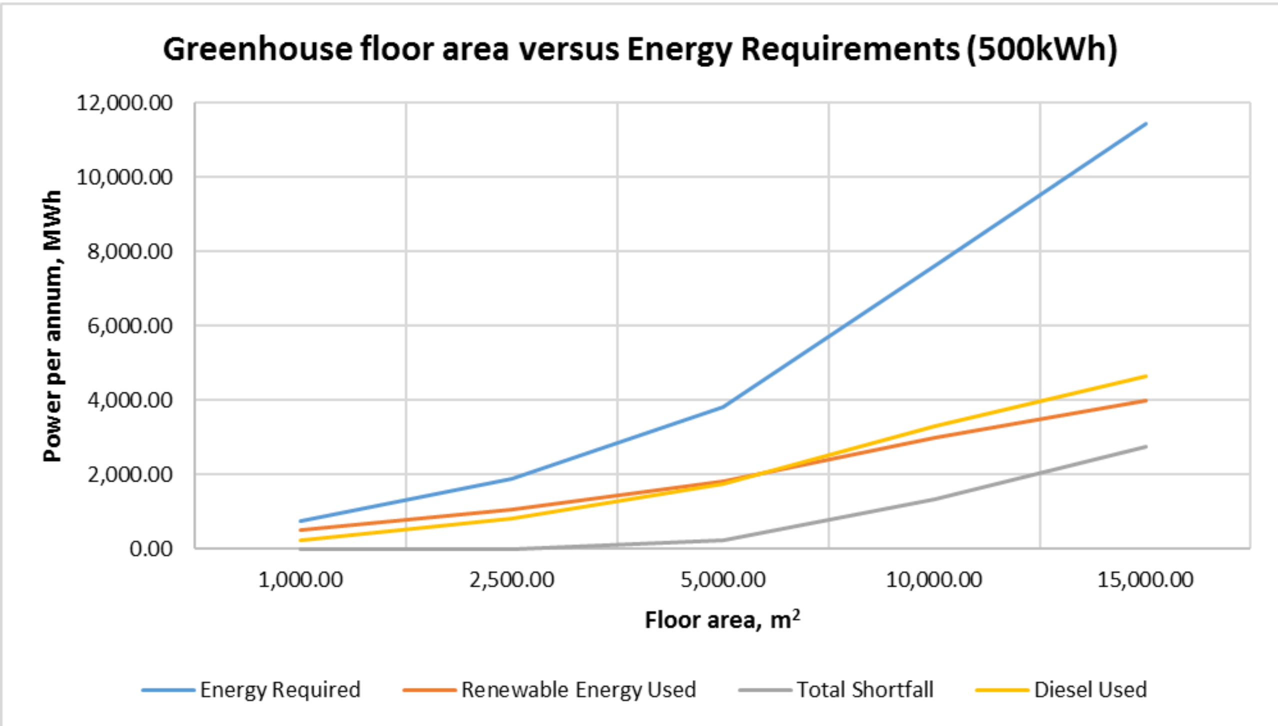


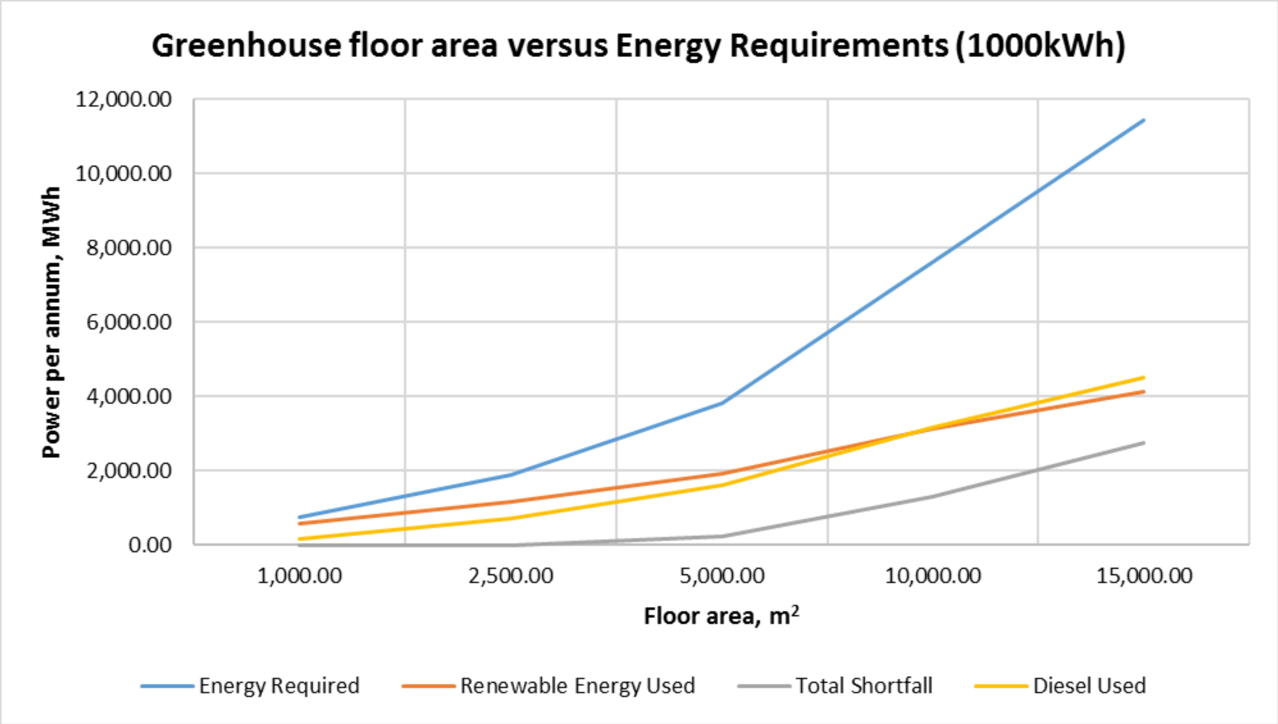
Greenhouse floor area versus energy needs met (5000kWh Battery)
Energy Needs Met
Days outside of thresholds
120.0%
100.0%
80.0%
60.0%
40.0%
20.0%
0.0%
5
4
4
3
3
2
2
1
1
0
1,000.00
2,500.00
5,000.00
10,000.00
15,000.00
Floor area, m2
Energy Requirements Met
Renewable Penetration
Number of Days outside thresholds

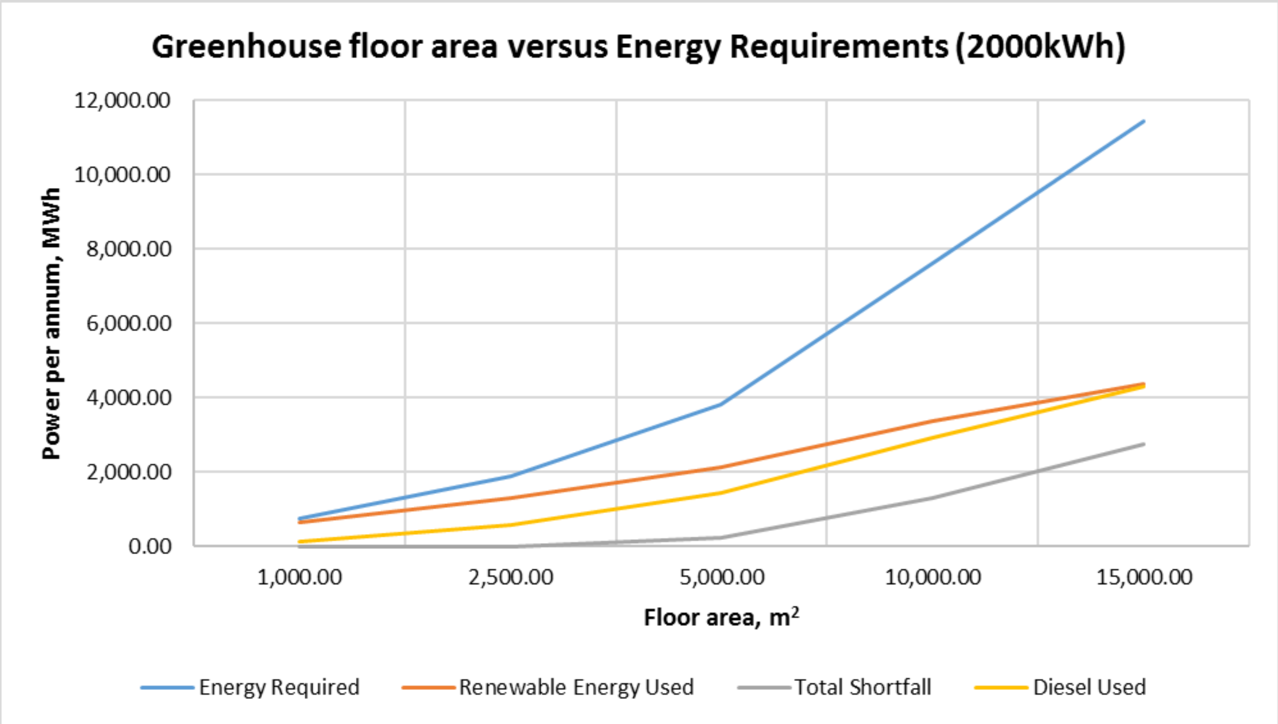
Temperature Range Chart for chosen scenario

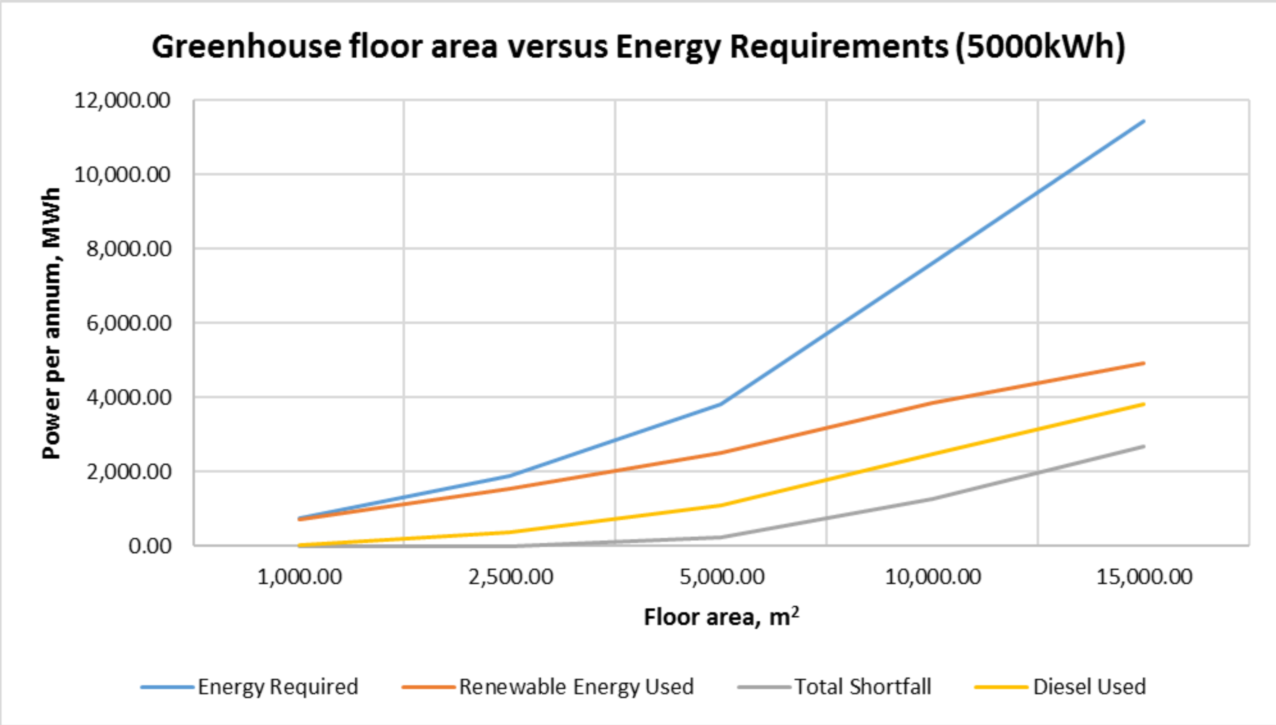


Relationship between Energy Requirements and Floor Area



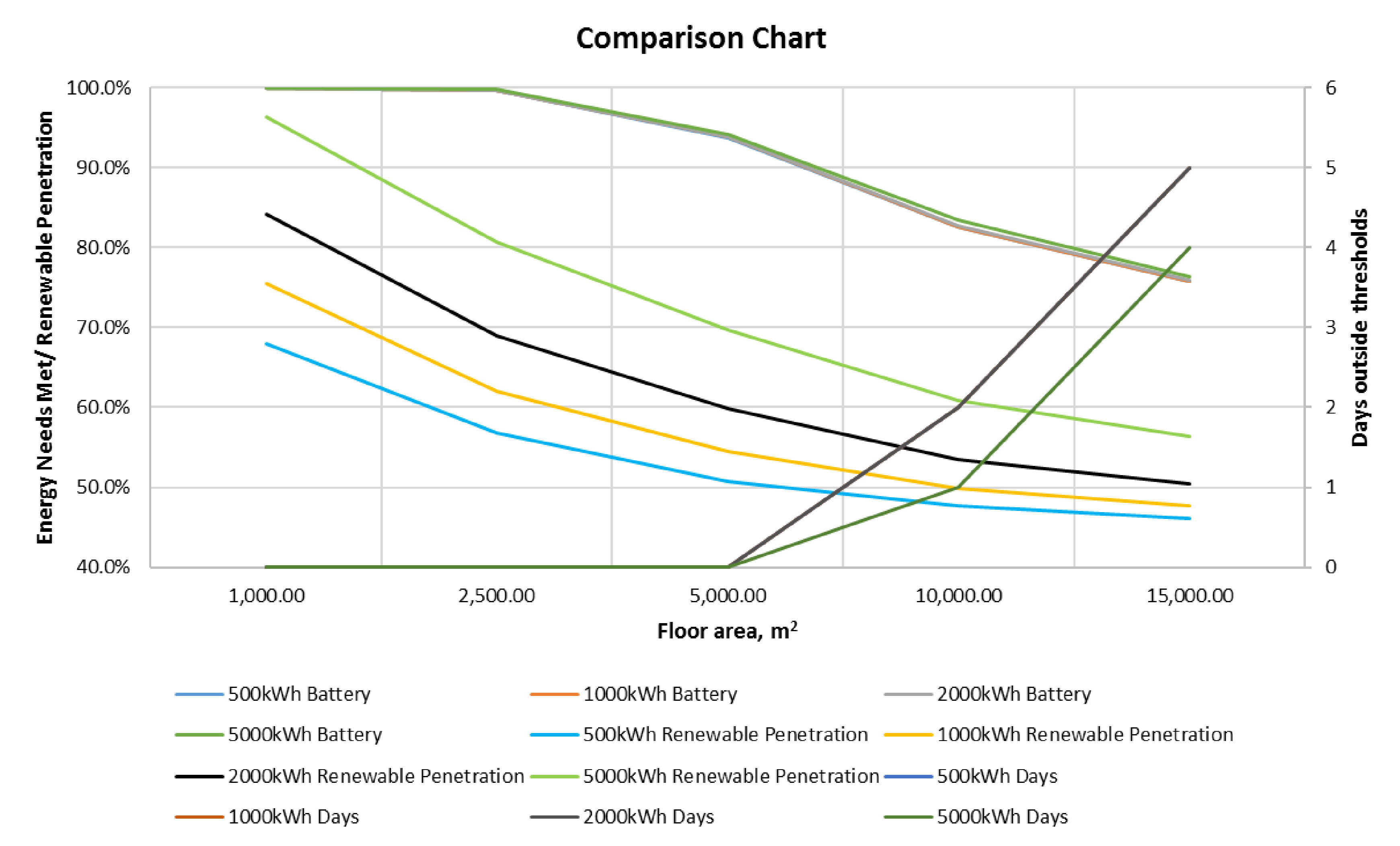

Greenhouse floor area versus Energy Requirements (1000kWh)
Power per annum, MWh
12,000.00
10,000.00
8,000.00
6,000.00
4,000.00
2,000.00
0.00
1,000.00
2,500.00
5,000.00
10,000.00
15,000.00
Floor area, m2
Energy Required
Renewable Energy Used
Total Shortfall
Diesel Used


Greenhouse floor area versus Energy Requirements (2000kWh)
Power per annum, MWh
12,000.00
10,000.00
8,000.00
6,000.00
4,000.00
2,000.00
0.00
1,000.00
2,500.00
5,000.00
10,000.00
15,000.00
Floor area, m2
Energy Required
Renewable Energy Used
Total Shortfall
Diesel Used



Greenhouse floor area versus Energy Requirements (5000kWh)
12,000.00
10,000.00
8,000.00
6,000.00
4,000.00
2,000.00
0.00
Power per annum, MWh
1,000.00
2,500.00
5,000.00
10,000.00
15,000.00
Floor area, m2
Energy Required
Renewable Energy Used
Total Shortfall
Diesel Used

Comparison of all iterations



Appendix N – Cost of Diesel Generation in Coober Pedy

From the Diesel Generator Datasheet, fuel consumption = 191g/kWh (LHV)

Density of Diesel Fuel = 0.84 kg/L [79]

LHV of Diesel = 43,400 kJ/kg [80]

Price = $1.45/L [51]

Need to convert fuel consumption to $/kWh

= 0.191 kg/kWh

Divide by Density

$$\frac{0.191\ kg/kwh}{0.84\ kg/L} = 0.2273\ L/kWh$$

Multiply by Price

$$\frac{\$1.45}{L} * \frac{0.2273L}{kWh} = \frac{\$0.3297}{kWh}$$

Cost of Diesel Electricity = $329.7/MWh

Appendix O – Financial Modelling Results

Scenarios four, five and six:

Description		Scenario 4, No Diesel, 1000m2 and 5000kWh Battery, Split Crop (Cucumber and Tomato)	Scenario 5, No Diesel, 1000m2 and 5000kWh Battery, No Summer Growing, Tomatoes only	Scenario 6, Diesel, 1000m2, Split Crop (Cucumber and Tomatoes)	Scenario 6, Diesel, 2500m2, Split Crop (Cucumber and Tomatoes)	Scenario 6, Diesel, 5000m2, Split Crop (Cucumber and Tomatoes)	Scenario 6, Diesel, 7500m2, Split Crop (Cucumber and Tomatoes)	Scenario 6, Diesel, 10000m2, Split Crop (Cucumber and Tomatoes)
Expansion CapEx	**Units**							
Greenhouse Capex - capitalised								
Greenhouse Materials + Equipment	real $'000	149	149	149	372	745	1,117	1,490
Miscellaneous	real $'000	-	-	-	-	-	-	-
Battery	real $'000	5,000	5,000	-	-	-	-	-
Total Capex (Excluding Cont.)	real $'000	**5,149**	**5,149**	**149**	**372**	**745**	**1,117**	**1,490**
Total	real $'000	**5,149**	**5,149**	**149**	**372**	**745**	**1,117**	**1,490**
Revenue Assumptions	**Units**							
Vegetable Price Assumptions								
Vegetable price curve 1	Description	Cucumber - Canadian Data Wholesale Price	Tomato - Canadian Data Wholesale Price	Cucumber - Canadian Data Wholesale Price	Cucumber - Canadian Data Wholesale Price	Cucumber - Canadian Data Wholesale Price	Cucumber - Canadian Data Wholesale Price	Cucumber - Canadian Data Wholesale Price
Vegetable price curve 2	Description	Tomato - Canadian Data Wholesale Price	Tomato - Canadian Data Wholesale Price	Tomato - Canadian Data Wholesale Price	Tomato - Canadian Data Wholesale Price	Tomato - Canadian Data Wholesale Price	Tomato - Canadian Data Wholesale Price	Tomato - Canadian Data Wholesale Price
Price inflation 1		20%	20%	20%	20%	20%	20%	20%
Price inflation 2		20%	20%	20%	20%	20%	20%	20%
Split Crop								
Split Crop?	On/Off	On	Off	On	On	On	On	On
Crop Information								
Crop Choice 1	Nominal	Cucumber	Tomato	Cucumber	Cucumber	Cucumber	Cucumber	Cucumber
Growing Period	Nominal	Summer		Summer	Summer	Summer	Summer	Summer
Crop Choice 2	Nominal	Tomato	Tomato	Tomato	Tomato	Tomato	Tomato	Tomato
Growing Period	Date	Autumn-Spring		Autumn-Spring	Autumn-Spring	Autumn-Spring	Autumn-Spring	Autumn-Spring
Winter Only Production	Nominal	Off	On	Off	Off	Off	Off	Off
Battery Energy fed to town	MWh/year		363					

Variable Price of Electricity	$/MWh		329.7					
LGCs?		Off	Off	Off	Off	Off	Off	Off
Renewable Energy consumed	MWh/year	733	882.6	397	915	1,636	2,253	3,799
Greenhouse Assumptions	**Units**							
Floor Area	m2	1,000	1,000.00	1,000	2,500	5,000	7,500	10,000
Battery Assumptions								
Charge/Discharge Capacity	kW	5000	5000					
Storage Capacity	kWh	5000	5000					
CapEx Cost	$'000	5000	5000	0	0	0	0	0
Battery Energy Used	MWh/year	336.38	518.07					
Opex	**Units**							
Fixed O&M								
Variable Cost of Running Greenhouse	$/m2	75.67	76.73	75.67	75.67	75.67	75.67	75.67
O&M Battery	$'000/yr	10.00	10.00	-	-	-	-	-
Diesel Used		Off	Off	On	On	On	On	On
Diesel Consumption	MWh/year			364.86	983.88	1930.41	2745.58	3475.87
Variable Diesel Cost	$/MWh			329.70	329.70	329.70	329.70	329.70
Diesel Cost per m²	$/m²			120.3	129.8	127.3	120.7	114.6
Discount Rate -	%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%
Outputs (BASE CASE)	**Units**							
Project Return Metrics								
Project NPV	$'000	**(4,462)**	**(3,765)**	**(877)**	**(2,507)**	**(4,850)**	**(6,615)**	**(8,006)**
Project IRR	%	**-7.2%**	**-3.8%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**
EBITDA								
FY19 EBITDA	$'000	**18**	**52**	**(28)**	**(83)**	**(159)**	**(213)**	**(253)**
FY20 EBITDA	$'000	**48**	**127**	**(57)**	**(168)**	**(322)**	**(432)**	**(512)**
FY21 EBITDA	$'000	**49**	**127**	**(59)**	**(172)**	**(330)**	**(442)**	**(525)**
FY22 EBITDA	$'000	**50**	**128**	**(60)**	**(176)**	**(339)**	**(454)**	**(538)**
FY23 EBITDA	$'000	**51**	**128**	**(62)**	**(180)**	**(347)**	**(465)**	**(551)**
Grid Connected Metrics								
Project Return Metrics								
Project NPV	$'000	**(4,462)**	**(3,765)**	**41**	**174**	**477**	**908**	**1,422**
Project IRR	%	**-7.2%**	**-3.8%**	**10.9%**	**12.7%**	**14.3%**	**15.9%**	**17.1%**
EBITDA								
FY19 EBITDA	$'000	**18**	**52**	**9**	**26**	**59**	**100**	**144**
FY20 EBITDA	$'000	**48**	**127**	**18**	**54**	**123**	**205**	**297**
FY21 EBITDA	$'000	**49**	**127**	**19**	**55**	**126**	**211**	**305**

FY22 EBITDA	$'000	**50**	**128**	**19**	**57**	**129**	**216**	**313**
FY23 EBITDA	$'000	**51**	**128**	**20**	**58**	**132**	**221**	**320**
LGC Metrics								
Project Return Metrics								
Project NPV	$'000	**(4,151)**	**(3,392)**	**(842)**	**(2,253)**	**(4,289)**	**(5,792)**	**(6,528)**
Project IRR	%	**-6.4%**	**-2.9%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**
EBITDA								
FY19 EBITDA	$'000	**47**	**87**	**(18)**	**(52)**	**(100)**	**(130)**	**(110)**
FY20 EBITDA	$'000	**102**	**193**	**(38)**	**(110)**	**(210)**	**(274)**	**(238)**
FY21 EBITDA	$'000	**101**	**190**	**(41)**	**(118)**	**(225)**	**(294)**	**(267)**
FY22 EBITDA	$'000	**99**	**186**	**(45)**	**(126)**	**(241)**	**(315)**	**(296)**
FY23 EBITDA	$'000	**97**	**183**	**(48)**	**(135)**	**(256)**	**(336)**	**(326)**

Scenario Seven

Description		Scenario 7, Diesel, 1000m2, No Summer Growing, Tomatoes Only	Scenario 7, Diesel, 2500m2, No Summer Growing, Tomatoes Only	Scenario 7, Diesel, 5000m2, No Summer Growing, Tomatoes Only	Scenario 7, Diesel, 7500m2, No Summer Growing, Tomatoes Only	Scenario 7, Diesel, 10000m2, No Summer Growing, Tomatoes Only
Expansion CapEx	**Units**					
Greenhouse Capex - capitalised						
Greenhouse Materials + Equipment	real $'000	149	372	745	1,117	1,490
Miscellaneous	real $'000	-	-	-	-	-
Battery	real $'000	-	-	-	-	-
Total Capex (Excluding Cont.)	real $'000	**149**	**372**	**745**	**1,117**	**1,490**
Total	real $'000	**149**	**372**	**745**	**1,117**	**1,490**
Revenue Assumptions	**Units**					
Vegetable Price Assumptions						
Vegetable price curve 1	Description	Tomato - Canadian Data Wholesale Price	Tomato - Canadian Data Wholesale Price	Tomato - Canadian Data Wholesale Price	Tomato - Canadian Data Wholesale Price	Tomato - Canadian Data Wholesale Price
Vegetable price curve 2	Description	Tomato - Canadian Data Wholesale Price	Tomato - Canadian Data Wholesale Price	Tomato - Canadian Data Wholesale Price	Tomato - Canadian Data Wholesale Price	Tomato - Canadian Data Wholesale Price
Price inflation 1		20%	20%	20%	20%	20%
Price inflation 2		20%	20%	20%	20%	20%
Split Crop						
Split Crop?	On/Off	Off	Off	Off	Off	Off
Crop Information						

Crop Choice 1	Nominal	Tomato	Tomato	Tomato	Tomato	Tomato
Growing Period	Nominal					
Winter Only Production	Nominal	On	On	On	On	On
LGCs?		Off	Off	Off	Off	Off
Renewable Energy consumed	MWh/year	209	504	960	1,379	1,772
Greenhouse Assumptions	**Units**					
Greenhouse Dimensions						
Floor Area	m2	1,000	2,500	5,000	7,500	10,000
Opex and SIB Capex	**Units**					
Fixed O&M						
Variable Cost of Running Greenhouse	$/m2	76.73	76.73	76.73	76.73	76.73
O&M Battery	$'000/yr	-	-	-	-	-
Diesel Used		On	On	On	On	On
Diesel Consumption	MWh/annum	157.63	413.50	838.07	1257.32	1677.96
Variable Diesel Cost	$/MWh	329.7	329.7	329.7	329.7	329.7
Diesel Cost per m^2	$/$m^2$	16.4	17.2	17.4	17.4	17.4
Project Cash Flows Discount Rate - WACC	%	8.0%	8.0%	8.0%	8.0%	8.0%
Outputs	**Units**					
Project Return Metrics						
Project NPV	$'000	**84**	**145**	**254**	**380**	**502**
Project IRR	%	**13.4%**	**11.8%**	**11.4%**	**11.4%**	**11.3%**
EBITDA						
FY19 EBITDA	$'000	**1**	**(0)**	**(2)**	**(4)**	**(5)**
FY20 EBITDA	$'000	**24**	**52**	**101**	**151**	**201**
FY21 EBITDA	$'000	**24**	**54**	**103**	**155**	**206**
FY22 EBITDA	$'000	**25**	**55**	**106**	**159**	**211**
FY23 EBITDA	$'000	**25**	**56**	**109**	**163**	**216**
Grid Connected Metrics						
Project Return Metrics						
Project NPV	$'000	**418**	**1,027**	**2,043**	**3,065**	**4,085**
Project IRR	%	**31.4%**	**31.0%**	**30.9%**	**30.9%**	**30.9%**
EBITDA						
FY19 EBITDA	$'000	**19**	**48**	**95**	**142**	**189**
FY20 EBITDA	$'000	**61**	**150**	**298**	**448**	**597**
FY21 EBITDA	$'000	**62**	**154**	**306**	**459**	**612**
FY22 EBITDA	$'000	**64**	**157**	**314**	**470**	**627**
FY23 EBITDA	$'000	**65**	**161**	**321**	**482**	**643**

LGC Metrics						
Project Return Metrics						
Project NPV	$'000	**148**	**304**	**559**	**819**	**1,067**
Project IRR	%	**18.8%**	**17.1%**	**16.4%**	**16.2%**	**15.9%**
EBITDA						
FY19 EBITDA	$'000	**9**	**19**	**35**	**50**	**64**
FY20 EBITDA	$'000	**39**	**90**	**173**	**254**	**333**
FY21 EBITDA	$'000	**39**	**89**	**171**	**252**	**331**
FY22 EBITDA	$'000	**39**	**88**	**170**	**250**	**329**
FY23 EBITDA	$'000	**38**	**88**	**168**	**249**	**327**

Scenario 8

Description		Scenario 8, Diesel, 500kWh Battery, 1000m2, Split Crop (Cucumber and Tomatoes)	Scenario 8, Diesel, 500kWh Battery, 2500m2, Split Crop (Cucumber and Tomatoes)	Scenario 8, Diesel, 500kWh Battery, 5000m2, Split Crop (Cucumber and Tomatoes)	Scenario 8, Diesel, 500kWh Battery, 10000m2, Split Crop (Cucumber and Tomatoes)	Scenario 8, Diesel, 1000kWh Battery, 1000m2, Split Crop (Cucumber and Tomatoes)	Scenario 8, Diesel, 1000kWh Battery, 2500m2, Split Crop (Cucumber and Tomatoes)	Scenario 8, Diesel, 1000kWh Battery, 5000m2, Split Crop (Cucumber and Tomatoes)	Scenario 8, Diesel, 1000kWh Battery, 10000m2, Split Crop (Cucumber and Tomatoes)
Expansion CapEx	**Units**								
Greenhouse Capex - capitalised									
Greenhouse Materials + Equipment	real $'000	149	372	745	1,490	149	372	745	1,490
Miscellaneous	real $'000	-	-	-	-	-	-	-	-
Battery	real $'000	500	500	500	500	1,000	1,000	1,000	1,000
Total Capex (Excluding Cont.)	real $'000	**649**	**872**	**1,245**	**1,990**	**1,149**	**1,372**	**1,745**	**2,490**
Total	real $'000	**649**	**872**	**1,245**	**1,990**	**1,149**	**1,372**	**1,745**	**2,490**
Revenue Assumptions	**Units**								
Vegetable Price Assumptions									
Vegetable price curve 1	Description	Cucumber - Canadian Data Wholesale Price	Cucumber - Canadian Data Wholesale Price	Cucumber - Canadian Data Wholesale Price	Cucumber - Canadian Data Wholesale Price	Cucumber - Canadian Data Wholesale Price	Cucumber - Canadian Data Wholesale Price	Cucumber - Canadian Data Wholesale Price	Cucumber - Canadian Data Wholesale Price

Vegetable price curve 2	Description	Tomato - Canadian Data Wholesale Price	Tomato - Canadian Data Wholesale Price	Tomato - Canadian Data Wholesale Price	Tomato - Canadian Data Wholesale Price	Tomato - Canadian Data Wholesale Price	Tomato - Canadian Data Wholesale Price	Tomato - Canadian Data Wholesale Price	Tomato - Canadian Data Wholesale Price
Price inflation 1		20%	20%	20%	20%	20%	20%	20%	20%
Price inflation 2		20%	20%	20%	20%	20%	20%	20%	20%
Split Crop									
Split Crop?	On/Off	On	On	On	On	On	On	On	On
Crop Information									
Crop Choice 1	Nominal	Cucumber	Cucumber	Cucumber	Cucumber	Cucumber	Cucumber	Cucumber	Cucumber
Growing Period	Nominal	Summer	Summer	Summer	Summer	Summer	Summer	Summer	Summer
Crop Choice 2	Nominal	Tomato	Tomato	Tomato	Tomato	Tomato	Tomato	Tomato	Tomato
Growing Period	Date	Autumn-Spring	Autumn-Spring	Autumn-Spring	Autumn-Spring	Autumn-Spring	Autumn-Spring	Autumn-Spring	Autumn-Spring
Winter Only Production	Nominal	Off	Off	Off	Off	Off	Off	Off	Off
LGCs?		Off	Off	Off	Off	Off	Off	Off	Off
Renewable Energy consumed	MWh/year	518	1,078	1,814	2,999	575	1,178	1,945	3,140
Greenhouse Assumptions	**Units**								
Greenhouse Dimensions									
Floor Area	m2	1,000	2,500	5,000	10,000	1,000	2,500	5,000	10,000
Battery Assumptions									
Charge/Discharge Capacity	kW	500	500	500	500	1000	1000	1000	1000
Storage Capacity	kWh	500	500	500	500	1000	1000	1000	1000
CapEx Cost	$'000	500	500	500	500	1000	1000	1000	1000
Battery Energy Used	MWh/year	121.11	162.62	177.56	187.35	177.89	263.2	308.49	328.87
Opex and SIB Capex	**Units**								
Fixed O&M									
Variable Cost of Greenhouse	$/m2	75.67	75.67	75.67	75.67	75.67	75.67	75.67	75.67
O&M Battery	$'000/yr	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Diesel Used		On	On	On	On	On	On	On	On
Diesel Consumption	MWh/annum	243.76	821.26	1756.65	3293.28	186.98	720.68	1628.31	3155.61
Variable Diesel Cost	$/MWh	329.70	329.70	329.70	329.70	329.70	329.70	329.70	329.70
		80.4	108.3	115.8	108.6	61.6	95.0	107.4	104.0

Discount Rate	%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%
Outputs	**Units**								
		Pasted	*Pasted*	*Pasted*	*Pasted*	*Pasted*	*Pasted*	*Pasted*	*Pasted*
Project Return Metrics									
Project NPV	$'000	**(982)**	**(2,430)**	**(4,724)**	**(7,841)**	**(1,237)**	**(2,492)**	**(4,664)**	**(7,740)**
Project IRR	%	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**
EBITDA									
FY19 EBITDA	$'000	**(14)**	**(61)**	**(136)**	**(228)**	**(5)**	**(45)**	**(115)**	**(206)**
FY20 EBITDA	$'000	**(27)**	**(123)**	**(274)**	**(460)**	**(8)**	**(89)**	**(231)**	**(414)**
FY21 EBITDA	$'000	**(28)**	**(126)**	**(281)**	**(472)**	**(9)**	**(92)**	**(236)**	**(424)**
FY22 EBITDA	$'000	**(28)**	**(129)**	**(288)**	**(484)**	**(9)**	**(94)**	**(242)**	**(435)**
FY23 EBITDA	$'000	**(29)**	**(133)**	**(295)**	**(496)**	**(9)**	**(96)**	**(249)**	**(446)**
Grid Connected Metrics									
Project Return Metrics									
Project NPV	$'000	**(289)**	**(98)**	**221**	**1,174**	**(707)**	**(450)**	**(85)**	**882**
Project IRR	%	**2.3%**	**6.7%**	**9.9%**	**13.9%**	**-0.6%**	**4.0%**	**7.4%**	**11.7%**
EBITDA									
FY19 EBITDA	$'000	**14**	**34**	**68**	**153**	**16**	**38**	**73**	**159**
FY20 EBITDA	$'000	**31**	**71**	**140**	**316**	**36**	**81**	**153**	**330**
FY21 EBITDA	$'000	**31**	**72**	**144**	**324**	**37**	**83**	**157**	**338**
FY22 EBITDA	$'000	**32**	**74**	**148**	**332**	**38**	**85**	**161**	**347**
FY23 EBITDA	$'000	**33**	**76**	**151**	**341**	**38**	**87**	**165**	**356**
LGC Metrics									
Project Return Metrics									
Project NPV	$'000	**(762)**	**(1,973)**	**(3,954)**	**(6,568)**	**(993)**	**(1,992)**	**(3,839)**	**(6,407)**
Project IRR	%	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**
EBITDA									
FY19 EBITDA	$'000	**6**	**(19)**	**(65)**	**(111)**	**17**	**1**	**(39)**	**(83)**

FY20 EBITDA	$'000	**12**	**(42)**	**(138)**	**(236)**	**35**	**(1)**	**(85)**	**(179)**
FY21 EBITDA	$'000	**9**	**(50)**	**(153)**	**(260)**	**32**	**(8)**	**(99)**	**(203)**
FY22 EBITDA	$'000	**6**	**(58)**	**(167)**	**(285)**	**29**	**(16)**	**(113)**	**(226)**
FY23 EBITDA	$'000	**3**	**(65)**	**(182)**	**(309)**	**27**	**(23)**	**(127)**	**(250)**

Description		Scenario 8, Diesel, 2000kWh Battery, 1000m2, Split Crop (Cucumber and Tomatoes)	Scenario 8, Diesel, 2000kWh Battery, 2500m2, Split Crop (Cucumber and Tomatoes)	Scenario 8, Diesel, 2000kWh Battery, 5000m2, Split Crop (Cucumber and Tomatoes)	Scenario 8, Diesel, 2000kWh Battery, 10000m2, Split Crop (Cucumber and Tomatoes)	Scenario 8, Diesel, 5000kWh Battery, 1000m2, Split Crop (Cucumber and Tomatoes)	Scenario 8, Diesel, 5000kWh Battery, 2500m2, Split Crop (Cucumber and Tomatoes)	Scenario 8, Diesel, 5000kWh Battery, 5000m2, Split Crop (Cucumber and Tomatoes)	Scenario 8, Diesel, 5000kWh Battery, 10000m2, Split Crop (Cucumber and Tomatoes)
Expansion CapEx	**Units**								
Greenhouse Capex - capitalised									
Greenhouse Materials + Equipment	real $'000	149	372	745	1,490	149	372	745	1,490
Miscellaneous	real $'000	-	-	-	-	-	-	-	-
Battery	real $'000	2,000	2,000	2,000	2,000	5,000	5,000	5,000	5,000
Total Capex (Excluding Cont.)	real $'000	**2,149**	**2,372**	**2,745**	**3,490**	**5,149**	**5,372**	**5,745**	**6,490**
Total	real $'000	**2,149**	**2,372**	**2,745**	**3,490**	**5,149**	**5,372**	**5,745**	**6,490**
Revenue Assumptions	**Units**								
Vegetable Price Assumptions									
Vegetable price curve 1	Description	Cucumber - Canadian Data Wholesale Price	Cucumber - Canadian Data Wholesale Price	Cucumber - Canadian Data Wholesale Price	Cucumber - Canadian Data Wholesale Price	Cucumber - Canadian Data Wholesale Price	Cucumber - Canadian Data Wholesale Price	Cucumber - Canadian Data Wholesale Price	Cucumber - Canadian Data Wholesale Price
Vegetable price curve 2	Description	Tomato - Canadian Data Wholesale Price	Tomato - Canadian Data Wholesale Price	Tomato - Canadian Data Wholesale Price	Tomato - Canadian Data Wholesale Price	Tomato - Canadian Data Wholesale Price	Tomato - Canadian Data Wholesale Price	Tomato - Canadian Data Wholesale Price	Tomato - Canadian Data Wholesale Price
Price inflation 1		20%	20%	20%	20%	20%	20%	20%	20%
Price inflation 2		20%	20%	20%	20%	20%	20%	20%	20%
Split Crop									
Split Crop?	On/Off	On	On	On	On	On	On	On	On

Crop Information									
Crop Choice 1	Nominal	Cucumber	Cucumber	Cucumber	Cucumber	Cucumber	Cucumber	Cucumber	Cucumber
Growing Period	Nominal	Summer	Summer	Summer	Summer	Summer	Summer	Summer	Summer
Crop Choice 2	Nominal	Tomato	Tomato	Tomato	Tomato	Tomato	Tomato	Tomato	Tomato
Growing Period	Date	Autumn-Spring	Autumn-Spring	Autumn-Spring	Autumn-Spring	Autumn-Spring	Autumn-Spring	Autumn-Spring	Autumn-Spring
Winter Only Production	Nominal	Off	Off	Off	Off	Off	Off	Off	Off
LGCs?		Off	Off	Off	Off	Off	Off	Off	Off
Renewable Energy consumed	MWh/year	641	1,310	2,140	3,375	733	1,535	2,502	3,867
Greenhouse Assumptions	**Units**								
Greenhouse Dimensions									
Floor Area	m2	1,000	2,500	5,000	10,000	1,000	2,500	5,000	10,000
Battery Assumptions									
Charge/Discharge Capacity	kW	2000	2000	2000	2000	5000	5000	5000	5000
Storage Capacity	kWh	2000	2000	2000	2000	5000	5000	5000	5000
CapEx Cost	$'000	2000	2000	2000	2000	5000	5000	5000	5000
Battery Energy Used	MWh/year	244.25	395.41	503.85	563.35	336.38	619.73	865.82	1055.8
Opex and SIB Capex	**Units**								
Fixed O&M									
Variable Cost of Running Greenhouse	$/m2	75.67	75.67	75.67	75.67	75.67	75.67	75.67	75.67
O&M Battery	$'000/yr	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Diesel Used		On	On	On	On	On	On	On	On
Diesel Consumption	MWh/annum	120.61	588.64	1437.17	2929.24	28.48	365.81	1084.81	2484.11
Variable Diesel Cost	$/MWh	329.70	329.70	329.70	329.70	329.70	329.70	329.70	329.70
Diesel Cost per Square Metre	$/m²	39.8	77.6	94.8	96.6	9.4	48.2	71.5	81.9
Discount Rate	%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%
Outputs (BASE CASE)	**Units**								
Project Return Metrics									
Project NPV	$'000	**(1,955)**	**(2,921)**	**(4,833)**	**(7,753)**	**(4,583)**	**(4,970)**	**(6,312)**	**(8,824)**
Project IRR	%	**-9.4%**	**0.0%**	**0.0%**	**0.0%**	**-8.3%**	**-10.5%**	**0.0%**	**0.0%**
EBITDA									
FY19 EBITDA	$'000	**4**	**(25)**	**(85)**	**(170)**	**13**	**7**	**(31)**	**(100)**
FY20 EBITDA	$'000	**12**	**(46)**	**(167)**	**(338)**	**38**	**24**	**(52)**	**(191)**
FY21 EBITDA	$'000	**13**	**(47)**	**(171)**	**(347)**	**39**	**25**	**(53)**	**(196)**
FY22 EBITDA	$'000	**13**	**(48)**	**(175)**	**(355)**	**40**	**26**	**(55)**	**(201)**
FY23 EBITDA	$'000	**13**	**(50)**	**(180)**	**(364)**	**41**	**26**	**(56)**	**(206)**

Grid Connected Metrics									
Project Return Metrics									
Project NPV	$'000	**(1,614)**	**(1,254)**	**(792)**	**246**	**(4,500)**	**(3,935)**	**(3,259)**	**(1,989)**
Project IRR	%	**-3.5%**	**0.9%**	**4.5%**	**8.8%**	**-7.5%**	**-3.1%**	**0.3%**	**4.2%**
EBITDA									
FY19 EBITDA	$'000	**18**	**43**	**82**	**169**	**17**	**49**	**94**	**187**
FY20 EBITDA	$'000	**41**	**93**	**172**	**353**	**45**	**111**	**204**	**395**
FY21 EBITDA	$'000	**42**	**95**	**176**	**361**	**46**	**113**	**209**	**405**
FY22 EBITDA	$'000	**43**	**98**	**181**	**371**	**47**	**116**	**214**	**415**
FY23 EBITDA	$'000	**44**	**100**	**185**	**380**	**48**	**119**	**220**	**425**
LGC Metrics									
Project Return Metrics									
Project NPV	$'000	**(1,683)**	**(2,365)**	**(3,925)**	**(6,322)**	**(4,271)**	**(4,319)**	**(5,250)**	**(7,183)**
Project IRR	%	**-7.6%**	**0.0%**	**0.0%**	**0.0%**	**-7.5%**	**-8.6%**	**0.0%**	**0.0%**
EBITDA									
FY19 EBITDA	$'000	**29**	**26**	**(1)**	**(38)**	**42**	**66**	**66**	**50**
FY20 EBITDA	$'000	**60**	**52**	**(7)**	**(86)**	**93**	**139**	**135**	**98**
FY21 EBITDA	$'000	**58**	**45**	**(20)**	**(108)**	**91**	**133**	**124**	**77**
FY22 EBITDA	$'000	**56**	**39**	**(33)**	**(131)**	**88**	**128**	**112**	**56**
FY23 EBITDA	$'000	**53**	**32**	**(47)**	**(154)**	**86**	**122**	**100**	**35**